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Inaugural ICRSME Virtual Conference: The Implications of COVID-19 for Science and Mathematics Education

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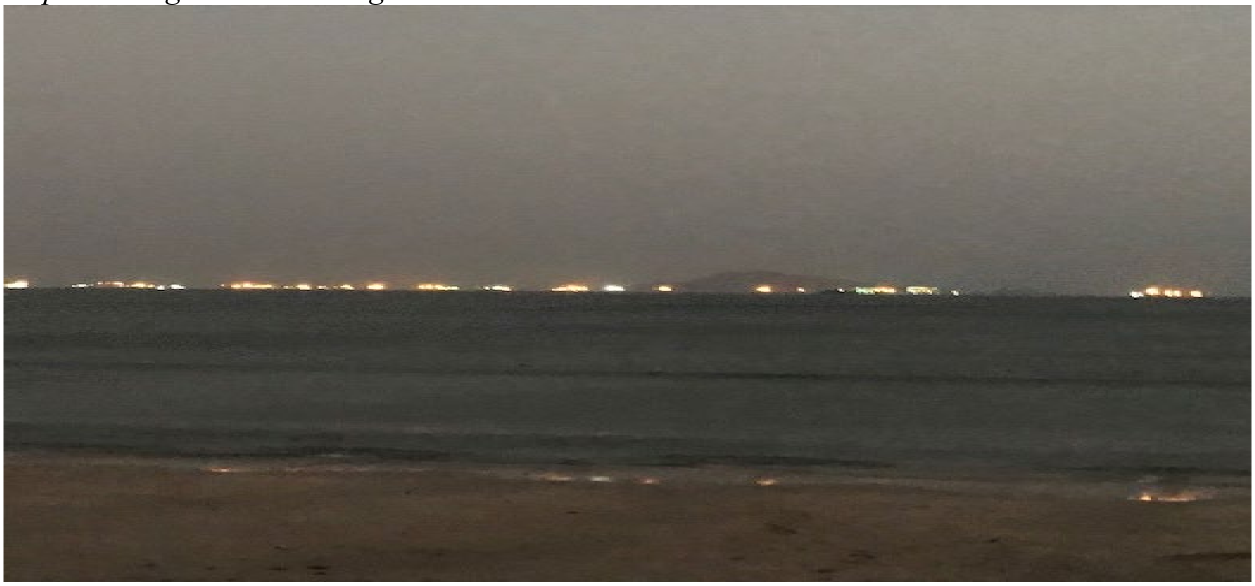
In the Spring 2020 editorial (Bloom & Quebec Fuentes, 2020a), our first after assuming editorship of EJRSME, we announced that the sixteenth consultation of the International Consortium for Research in Science & Mathematics Education (ICRSME) would take place in Spring of 2021. Soon after publishing the editorial, however, we realized our plans would have to change. In March of 2020, we traveled to Panama to meet with potential education collaborators and to scout out locations for the consultation presentations, hotel accommodations, and local dining and entertainment options. When we arrived in Panama, Coronavirus was still largely contained in China and other eastern countries and had not yet been detected in Panama. During our visit, Panama experienced its first case of COVID-19 and schools across the country were immediately closed (GardaWorld, 2020a). We returned to the U.S. just days before Panamanian officials suspended all international air travel into or out of the country (GardaWorld, 2020b). Because of the long-lasting, global impact of COVID-19, we announced in our summer editorial (Bloom & Quebec Fuentes, 2020b) that we would, instead, host a virtual conference.

The virtual conference took place March 20, 2021 with over 140 registered participants indicating that, despite setbacks, ICRSME friends know how to be flexible. During the opening session of the conference, we shared an image from a beach near Panama City depicting the night horizon over the Pacific Ocean (Figure 1). The lights in the distance were ocean liners lined up in a queue, waiting for their turn to pass through the Panama Canal. Each night they would line up and wait … and wait… and wait. Over the past year, we have all had to practice the art of waiting. We have waited to return to face-to-face instruction, to socialize with friends and family, and to get vaccines. The ICRSME XVI Consultation will take place, but we will have to wait a bit longer. Because of uncertainties such as travel restrictions, vaccine availability, and university finances, among many others, we are planning to hold the consultation in Panama in Spring of 2023.

As we indicated in the summer editorial, however, we see the challenges presented by COVID-19 also as an opportunity to grow ICRSME participation and further strengthen the ties between ICRSME and EJRSME. Throughout its history, ICRSME has held consultations roughly every other year; we now hope to fill these gaps with virtual conferences. During this past conference, we had 24 asynchronous presentations, which are available for your viewing on our website, as well as 27 synchronous round table discussions that occurred during two breakout sessions, addressing an array of aspects related to mathematics and science education. We were pleased to have international participation from countries around the globe including Australia, Ghana, Germany, Netherlands, Panama, and South Africa.

Figure 1
Ships Waiting to Pass Through the Panama Canal



In addition to ICRSME participant presentations, we also had four fantastic plenary sessions. The theme of the conference aligned with the foci of the editorials published in 2020, namely the gaps in science and mathematics education revealed by the COVID-19 pandemic; ways in which science and mathematics educators were adapting their instruction to deal with the pandemic teaching conditions; and ways in which we, as educators, can address the growing public distrust in science and mathematics (Bloom & Quebec Fuentes, 2020b, 2020c; Quebec Fuentes & Bloom, 2020).

The layperson must possess knowledge about the natures of science and mathematics in order to make sense of complex, data-rich scientific phenomena, whether it be the current COVID-19 pandemic, genetic medicine, changing public health recommendations, or climate change. The first plenary session, *Sunk Shore: Exploring the Public's Relationship to Data through Climate Science*, featured Carolyn Hall, marine scientist, science communicator, and professional dancer. She described a walking tour "into the future" of Manhattan, New York, offered by the non-profit organization Underwater New York, that engages the public in thoughtful discourse about climate change and the potential local effects that could result over time. Daniel Alston, Assistant Professor of Elementary Science Education at the University of North Carolina at Charlotte (and EJRSME Associate Editor) described how science and mathematics educators can engage their students in ways that address the challenges that Carolyn overcomes in her work communicating data-dense science to non-scientists.

In the second plenary, *Interpreting and Understanding COVID-19 Data*, Cameron Byerley, Assistant Professor of Mathematics and Science Education at the University of Georgia discussed how media representations of COVID-19 data are often misleading or misunderstood by much of the general public. Based on knowledge gained through conducting interviews about citizens' interpretations of COVID-19 data and their representations, she and her research team at COViD-Taser are developing ways to represent such quantitative data so the public can better understand the meaning behind the data and can use this knowledge to make informed decisions regarding their own health and that of others with respect to the risk of contracting COVID-19 and the COVID-19 vaccine. The team's work also has important implications for the teaching and learning of mathematics, specifically related to relative size and the interpretation of slope in linear and log-scale graphs.

The third plenary, *The Science Behind SARS-CoV-2 and COVID-19*, was delivered by Dr. Daniel Janies, the Carol Grotnes Belk Distinguished Professor of Bioinformatics and Genomics at the Bioinformatics Research Center and Dr. Ian C. Binns, Assistant Professor of Elementary Science Education, both from the University of North Carolina at Charlotte. During this interview-style session, they discussed the nature of science (NOS) in context of coronavirus origins, countermeasures to disease spread, evolution of viral variants, and ways to address misinformation regarding COVID-19. They also fielded questions from the audience, many of which pertained to the current roll out of the various COVID-19 vaccines and the potential of reaching herd immunity through vaccination campaigns.

In the final plenary session of the day, a panel of colleagues shared *International Perspectives on the COVID-19 Pandemic*. The panel consisted of:

- Nadia De León: member of the National Research System, currently affiliated at Instituto de Investigaciones Científicas y Servicios de Alta Tecnología and Universidad Santa Maria la Antigua in Panama;
- Ebenezer Ageh: petroleum engineer who has taught chemical engineering, mathematics, and physics in Nigeria;
- Patricia Morrell: Head of the School of Education at the University of Queensland, Australia;
- Gabriela Jonas-Ahrend: faculty at Paderborn University in Germany, where she is a member of the “Fachgebiet Technikdidaktik” (technical didactics); and
- Forrest Bradbury: lecturer at Amsterdam University College, Netherlands for introductory physics, applied mathematics, energy science, physics lab courses, nanoscience, and the Maker Lab course.

The panelists shared their personal experiences with COVID-19 in their context, including issues such as the government’s response to the pandemic, the variable impact on different sectors of the school population, implications for pre-service teacher education, and adaptations to instruction to accommodate remote learning.

All of the various activities that occurred throughout the virtual conference could not have happened without support. In particular, we would like to acknowledge Ellie Stackhouse, Texas Christian University (TCU) graduate student and ICRSME treasurer and conference coordinator; Jonathan Crocker, TCU graduate student and EJRSME managing editor; and Patrick Herak, ICRSME website designer. We would also like to thank the 12 EJRSME Associate Editors that moderated conference sessions: James Álvarez, Stacey Britton, Stephen Burgin, Malcolm Butler, Danxia Chen, Rita Hagevik, Hayat Hokayem, Chris Long, Cherie McCollough, Samuel Otten, Julie Westerlund, and Robert Wieman. We greatly appreciate our gold sponsor, Andrews Institute of Mathematics and Science Education, and the support of our home institutions, Dallas Baptist University and Texas Christian University, for professional leave and graduate student support, respectively.

Based on the success of the 2021 virtual conference, we are already beginning to plan another for Spring of 2022. We hope you will consider participating and that next year we can expand even further around the globe to increase our international participation. More details will be forthcoming through EJRSME, the ICRSME website, and the new ICSRME Newsletter.

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Like the Kids Do: Engineering Design in Middle-School Science Teacher Professional Development

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ABSTRACT

This study describes how 19 middle-school science teachers responded to an engineering design task in the context of water quality and environmental science professional development (PD). The study relies on teacher created prototypes, presentations, graphic organizers, and qualitative memos to illustrate the challenges and successes of the PD. In the findings, we discuss two major themes that emerged from the data sources regarding teachers' focus on resource management and pedagogical understanding. Finally, we include lessons learned as we move forward as science teacher educators in an era where teachers are challenged to continue to adapt to pedagogical paradigm shifts within science education.

Keywords: middle-school science, engineering design, case study

Introduction and Background

While the Next Generation Science Standard (NGSS) (NGSS Lead States, 2013) included engineering within practices and disciplinary core ideas, professional development (PD) that helps current science teachers develop an understanding of and instructional competence for engineering as a component of STEM instruction is important. This was made evident by a review of the landscape for K-12 engineering (Moore, et al., 2015) that provides insight into the challenges for teachers with widespread adoption of NGSS. In addition, the new initiatives suggested that subjects that have traditionally been taught separately, now be integrated (Guzey, et al., 2016). Lesseig, et al. (2016) stated that while there is still no set definition for STEM education, general agreement indicates that it should involve rigorous units, be problem based, and help build 21st century skills. More recently, STEM has been conceptualized as a "meta-discipline that bridges discrete disciplines such as science, technology, engineering and mathematics using application or processes from each to create knowledge as a whole" (Herro & Quigley, 2017, p. 416). As such, middle-school science teachers who, in many states, are generalists, are particularly challenged as they are being asked to teach a process for which they have no point of reference (Brophy, et al., 2008).

A possible starting point is to recognize that science and engineering practices differ in several ways (Feille, Nettles, & Weinburgh, 2017). Science practices focus on changing one variable at a time while engineering practices involve changing several parts of a system to improve the system as a whole. Engineering practices are cyclical with many feedback loops. This recognition is necessary but not sufficient if middle-school teachers are expected to include engineering design within their science instructional time. An additional starting point is to help teachers identify how the process of engineering design can be situated within their pedagogical paradigm of student-centered learning and instruction design. Engineering design tasks are a concrete way to implement student-centered strategies such as collaboration, open-ended products/solutions, teacher as facilitator, and metacognition (Cunningham & Carlsen, 2014). However, to encourage the use of engineering design instructional tasks, teachers need to experience authentic problems for which engineering design is appropriate (Guzey, et al., 2014; Sun & Strobel, 2013). They must also experience ways that the process of engineering design can enhance and expand the science content taught in their grade level and further support the pedagogical demands of the student-centered/inquiry-based classroom (Estapa & Tank, 2017; Guzey et al., 2014).

Thus, the science education community has been slowly building a much-needed body of research on teacher PD programs for successful K-12 engineering education (Yoon, et al., 2013). Van Haneghan, et al. (2015) found a positive correlation between teacher self-efficacy and a teacher's beliefs about their students' abilities to engage in engineering practices. In addition, Lesseig et al. (2016) found that providing opportunities for teachers to observe struggling students succeed with the more challenging engineering design tasks proved to be an important experience for many of their teachers participating in the engineering design PD. Estapa and Tank (2017) found that after a PD focusing on integrating content within engineering design, teachers were able to "identify multiple ways in which engineering design could be used as a context for integration" (p. 14). Actually accomplishing integration, however, was limited due to a multiple number of challenges. Teachers required more support in the planning and enactment of lessons to support integration of content (Estapa & Tank, 2017).

The purpose of this exploratory study is to investigate how middle-school science teachers respond to an authentic and appropriate engineering design task within a summer PD. In doing so, the research team approached the research asking what patterns emerge as teachers engage in an authentic engineering design task conceived for middle-school students?

Conceptual Framework

The overlap of socio-cultural constructivism (Vygotsky, 1986) and situated learning theory (Hung & Chen, 2001; McLellan, 1996) is used as the conceptual foundation of the study. Socio-cultural constructivism theory stresses the construction of knowledge through social interactions. From this perspective, peers and teachers provide learners with observable examples of the norms and practices of the culture. Language (as a commonly used social tool) becomes highly important within the community/culture as a means by which the individual and the community develop. Leontiev (1981) stated that an individual appropriates the socially available psychological tools of the community(ies) in which the individual resides. The teachers within this study constitute a community and work in collaborative groups. According to socio-cultural constructivism, they should exhibit new social language and actions as they integrate engineering practices into their STEM learning and instruction.

Situated learning theory has epistemological roots in the belief that learning is a contextualized, on-going process. It stresses that knowledge is created as "individuals interact with their environment to achieve a goal" (Whitworth, et al., 2017, p. 701) and that the setting in which the knowledge is used is important in determining what is learned. By focusing on the intersection of learning and social conditions, situated learning theory helps explain how professional skills are acquired (Vincini, 2003).

Research Design and Methods

This single case study investigates the response of a small group (N=19) of middle-school teachers to an engineering design task as presented in a summer PD. The teachers making up this case were all new to engineering and classroom-based engineering design tasks. The case study approach allows for more depth of study, investigates a series of connected events that occur in or over a specific time and place, and are deeply embedded in the context of the case (Flyvbjerg, 2001). Teacher design solutions, presentations, and graphic organizers paired with research team observation and qualitative memos provided the data set for the study. An emergent thematic analysis provided direction for the study and is described in more detail below.

Participants

Middle-school science teachers from a large metropolitan area in the southwest were recruited for a PD that focused on environmental science with an emphasis on watersheds and water quality. Although one district (X) was the primary focus for recruiting, advertising flyers were sent to five other districts. Interested teachers completed an application and were selected based on requirements from the funding agency (e.g., teacher of science and not meeting the federal designation of "highly qualified"). Nineteen teachers (representing three districts) of varied backgrounds and teaching assignments participated (see Table 1).

Table 1
Participant Demographics

Category	Subcategory	Frequency (n)	Proportion (%)
Gender			
	Male	5	26%
	Female	14	74%
Race/Ethnicity			
	African American	5	26%
	American Indian	1	5%
	Hispanic	2	10%
	White	11	58%
University Degree			
	Other than science or education	7	37%
	Elementary Education	5	26%
	Science	7	37%
District			
	X	17	90%
	Y	1	5%
	Z	1	5%
Years Teaching Experience			
	≤ 5	5	26%
	6 to 10	8	42%
	≥ 11	6	32%

Study Context: The Professional Development

Changing teacher's practice is difficult, taking time and often requiring multiple exposures to professional development (Luft & Hewson, 2014). Therefore, the PD providers utilized a design containing elements found to be most effective: content specific (Garet, et al., 2001), long-term (Hauck & Campbell, 2014; Loucks-Horsley, et al., 2010), and learner centered (Loucks-Horsley et al., 2010). The teachers participated in 10 days (55 hours) during the summer with an academic year follow-up. The PD providers included three college of education faculty members from two local institutions. One faculty served as a pedagogical expert in science teaching, one as a language instruction expert in teaching to English language learners, and a third as a content expert in environmental issues. This study focuses on the engineering design task, taking place over five days (day 1 and 6-9) of the summer portion of the PD and does not include the other four days of the summer PD or the academic year follow-up (see Table 2).

Table 2
PD Day by Day

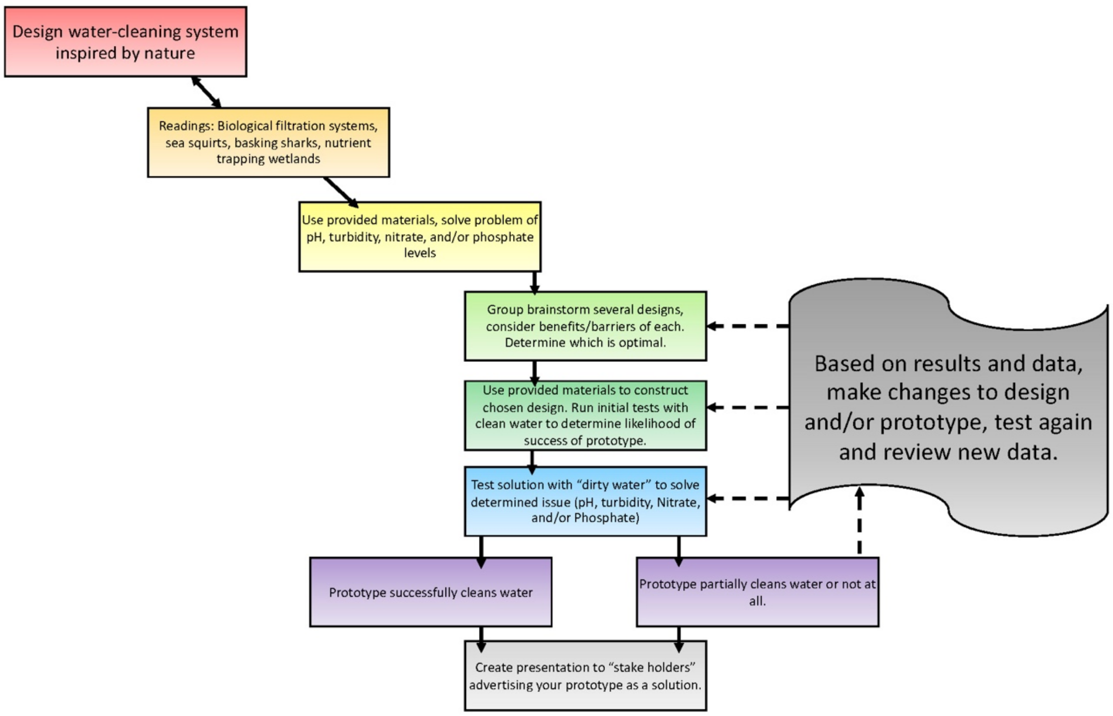
Day 1	Day 2	Day 3	Day 4	Day 5
Watershed Introduction	Continue water testing.	ELL Topics	Field Trip – Water Treatment Plant	Debrief Day & ELL Topics

Day 6	Day 7	Day 8	Day 9	Day 10
Define the Problem	Conducting Background Research & Specify Requirements	Prototype Development and Optimization	Finalize Prototype and Present Solution	Classroom implementation & ELL Topics

The science content focused on watersheds and the environmental issues surrounding water quality including content about water contamination, how to test water for the presence of typical contaminates, and features of the local watershed. To model learner-centered pedagogical practices, in addition to ELL pedagogical support, the PD team decided to include an engineering design task that required using scientific knowledge of water and the characteristics of clean water to design a water filtration system. It was communicated to the teachers at multiple points to address the engineering design task as they thought their students might, engaging in the task as learners following the process of engineering design (see Figure 1). This same engineering design task was piloted by two members of the research team with upper-elementary and middle-school students in a week-long, University-based workshop earlier in the summer which allowed the researchers to compare the practices of the teachers with those of student learners (see Feille, Nettles, & Weinburgh, 2017)

Figure 1

Process of Engineering Design for Designing a Water Filtering System Inspired by Nature



Define the Problem

Initially, teachers were introduced to the local watershed through an interactive investigation using Google Maps and mini-lessons. Google Maps provided visuals of the local watershed. Mini-lessons provided information about the primary components of water quality including river bank evaluation, pH, temperature, turbidity, benthic macroinvertebrates, coliform bacteria, dissolved oxygen, nitrates, and phosphates. In addition, the teachers visited a near-by, human-made collection pond to collect observations and qualitative data regarding the quality of the site and interpreted student-collected water quality data for the site. Relating to questions of water quality, the teachers used a LaMotte® water-testing kit to become familiar with standard tests used to investigate and determine the quality of a water sample. The teachers followed test directions provided in the kit to learn about the significance of and practice measuring pH, temperature, nitrate and phosphate levels, and turbidity on both clean (tap water) and dirty (with added nitrates, phosphates, and soil to increase turbidity) water samples. After the content introduction the teachers were given the engineering design task requiring them to plan a system that was inspired by the water-cleaning processes of nature.

Conduct Background Research

To gain an understanding of how processes in nature work to clean water, the teachers researched natural filtering systems. They were provided sample readings about biological filtration systems, sea squirts, flamingos, basking sharks, whales, and sediment trapping in wetlands as well as conducted their own internet searches. Background research ended with table discussions about filtering techniques and possibilities for transfer to human-made systems and the ways in which humans have taken advantage of these processes to purify water through biomimicry (for example, constructing wetlands for wastewater filtration).

Specify Requirements

To address the engineering design task, the PD providers introduced the teachers to the following supplies: plastic hosing, A/C powered water pumps, plastic shoe bins, fish tank filter bags and filter media, coffee filters, sponges of various sizes, mesh bags, gravel, sand, duct tape, and twine. The PD providers asked groups to identify one or more water-quality issue to focus on for their filtration system (e.g pH, turbidity, or nitrate and/or phosphate levels). The PD providers then allowed teachers access to the above introduced materials as well as any other materials found in the classroom and supply closet that would help them meet the identified requirements for their initial water filtration prototype.

Prototype Design and Solution Optimization

Next, teacher groups designed and built their prototypes. Prior to building, it was expected that groups considered and discussed several designs. When an agreed upon design was selected, the teachers used the materials provided (and others they collected along the way) to construct their filtration devices. Once their device was built, they tested it for structural issues (i.e. leaks) with a small amount of clean water before they tested their process on dirty water. Groups then determined if their solution met the requirements defined above, what adjustments they needed to make, and made these changes to optimize their solution. Group members recorded any designs, changes, and test results in their journals.

Communicate Solutions

Once they determined a final solution, each group shared their progress and results using a multimedia presentation (such as video, PowerPoint, or Prezi). Groups were encouraged to identify the audience for their presentation; some of the presentations identified specific audiences such as policy makers or investment firms, while others indicated stakeholders who might be interested in alternate modes of water cleaning. Criteria for the presentations were not established per a rubric or checklist so that the teachers were free to communicate what they felt was important to share based on what they learned throughout the process as long as they described their goals and the methods they used to meet their goals. Their decisions made during this process provided data regarding their understanding of the purpose and process of engineering design as well as the scientific content regarding water quality.

After the group presentations, the PD providers showed videos of previous student presentations and displayed a collection of student-constructed prototypes (see Figure 2) as comparisons to the teacher-constructed prototypes (see Table 3). The influence of these videos can be seen in the teachers' discussions concerning the process of engineering design. Teachers were given time to debrief as they compared their design to the student designs as they considered the implications for classroom practice.

Figure 2
Examples of Student Prototypes

Table 3
Comparing Student and Teacher Prototypes

Student Prototypes	Teacher Prototypes
Universal use of water pumps and gravitational force	Primarily (3 out of 4) relying solely on gravitational force
Invested in multiple iterations of prototype	Often relied on first design, only adding leak prevention
Used and modified (sometimes permanently) all available supplies	Used all available supplies, but only modified those seen as disposable (e.g. water bottles, coffee filters, paper towels)
Experimented with various forms of filtration including fish tank filters and filter media (e.g. sand, gravel, charcoal).	Relied on familiar materials and filtration tools (e.g. water bottles, gravel, and coffee filters)
Primarily unconcerned with amount of materials used – not conservation minded	Primarily concerned with conserving materials and not wasting or needing to throw away products

Data Collection

Multiple sources of data were used to investigate the teachers' experiences with the engineering design task It was the intention of the research team to first mimic the experiences as provided to upper-elementary and middle-school students in the summer workshop Diving Deeper (Feille, Nettles, & Weinburgh, 2017) as well as challenge the teachers to relate their experiences as learners back to possibilities within their own classrooms. Products created by the teachers as they designed solutions to the engineering design task (journal entries, graphic organizers, prototypes, and final presentation) were combined with photos, videos, and research team memos to provide the data for this study. The research team included two of the PD providers and two additional researchers. Two members of the research team were also the designers and facilitators of the Diving Deeper workshop for students. All four members of the research team collected photographs, field observations, and memos.

Teacher Design Solutions

In groups of three to four, the teachers used the process of engineering design to approach the problem of removing contaminates from a dirty water sample inspired by the water cleaning processes found in nature. Groups were asked to develop, test, and optimize a prototype solution with a clean water sample before evaluating their solution with dirty water. Teacher prototypes were photographed, and tests were videotaped for both the research team and for the teachers to use in their multimedia presentations.

Figure 3
Teacher Constructed Products

Figure 3 shows the four final group prototypes. Throughout the process, teachers were asked to record notes of their plans, changes, trial results, and questions in their participant journals. Once each group chose and built an optimized solution, they produced a technical drawing that detailed what materials were used and how they were assembled. Each drawing was to scale and included multiple views of the prototype solution (front, top, bottom, left or right, and/or exploded views). These drawings were recorded in the participant journals.

Teacher Presentations

As a final step in their engineering design task, groups shared their prototype solution and the results of their tests in a multimedia presentation. The groups were allowed to choose the method in which they presented their goals, prototype, and findings. The presentations were videotaped, providing additional data regarding the teachers' thought processes and decision making during their engineering design task.

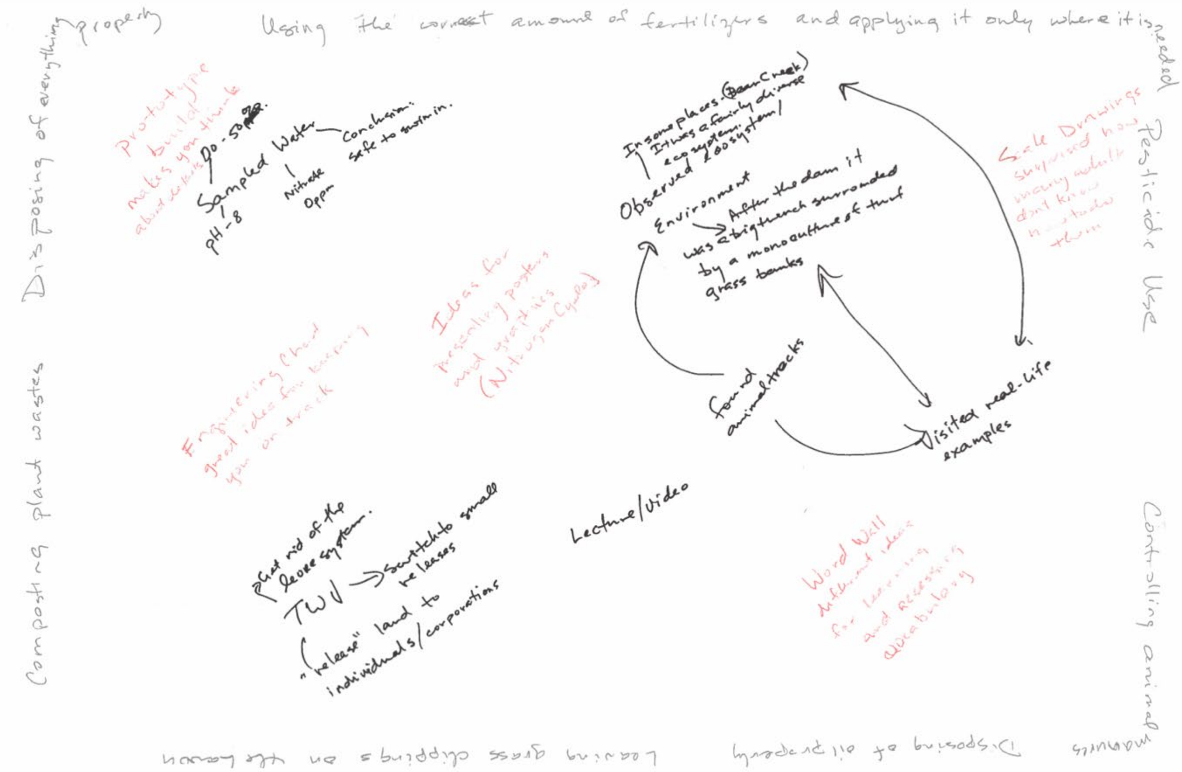
Qualitative Memos

Throughout the engineering design task, the PD providers held large and small group discussions with the teachers. During the discussions, members of the research team recorded memos detailing teacher responses and ideas. These memos provide further qualitative data regarding the teachers' ideas and thoughts concerning the process of engineering design and their experiences solving the problem.

Graphic Organizers

Over the course of the PD, teachers constructed graphic organizers around the topics and activities addressed. The graphic organizers were constructed over three completed iterations. The first iteration asked teachers to identify ways in which they could have an impact on their watershed and list these impacts along the one-inch margin of an 11x17 sheet of paper. During the second and third iterations, teachers brainstormed three to five meaningful events or topics covered through the PD using a different colored pencil for each iteration. These three to five events served as nodes within the graphic organizer. Although they were encouraged to do so, in most cases, the teachers did not identify connections of ideas or events across the graphic organizer but instead constructed several individual and isolated graphic organizers stemming from the identified nodes. Figure 4 shows an example graphic organizer. Although the graphic organizers offer some evidence of conceptual understanding of the pedagogical tool or scientific concept identified, they were not used as an assessment tool. The graphic organizers were used to identify the events and concepts the teachers found meaningful for their own pedagogical and content understanding.

Figure 4
Example Graphic Organizer



Data Analysis

This research included a number of "episodes" (Stake, 2010, p. 133) made up from the teacher constructed prototypes, presentations, graphic organizers, and research team observations and qualitative memos. Episodes are specific isolated behaviors or events. Through a reiterative process, the research team worked as individuals as well as collectively to identify "patches" of meaning within the multiple sources of data. Patches of data are the episodes that become more useful, revealing meaning within the data (Stake, 2010). The team then synthesized the patches using emergent themes regarding the teachers' responses to the engineering design task.

Emergent themes were initially identified through observations and research team memos. Throughout data collection, research team memos referred frequently to teacher use of resources, demonstrations of content understanding compared to discussions of classroom implementation. Individually, research team members analyzed the patches of data for evidence of the primary themes as well as any other secondary themes that may emerge and then compared analytical findings during regular research-team meetings (Ely, et al., 1997). Table 4 identifies these primary and secondary themes.

Table 4
Primary and Secondary Themes

Resource Management	Attention to Content
Disposable over reusable	Pedagogical focus
Modification of materials	Misconceptions maintained
Familiarity vs novelty	Feasibility of biomimicry design
Time	Process of engineering design

Several techniques suggested by Lincoln and Guba (1985) and Glesne (2006) were utilized to increase the trustworthiness of the research claims. Credibility was increased by having prolonged engagements with the teachers, multiple data sources, multiple researchers, and clarification of researcher bias. Confirmability was established through audit trails, multiple data sources and reflexivity.

Findings

Two primary themes emerged during field observations and were further investigated through the data analysis. First, the teachers were consistently mindful of resource management. This was seen in the selection of materials as well as designs for filtration systems. Second, the teachers were focused on a pedagogical understanding rather than a science content or understanding the process of engineering design.

Resource Management

Almost immediately upon being given the engineering design task, one teacher expressed the desire to use an empty water bottle, bottled water was provided as refreshment and not intended as a construction material. This resulted in other teachers selecting to use the bottles (even to the extent of drinking the water to provide an empty bottle). Like the students, the teachers were encouraged to use any available material in the room and supply closet. While the students gravitated more towards the supplies laid out on a table, the teachers actively sought out alternatives. The teachers talked about having used bottles for science experiences and how easy/cheap empty water/cola bottles were to use and proceeded to use the water bottles as reservoirs. Essentially most groups replaced water bottles for the provided plastic shoe boxes, which the teachers actively avoided. With regard to the lack of use of the shoe boxes, Ruby (pseudonyms are used) stated that the teachers viewed the bins [shoe boxes] as reusable which dissuaded them from selecting that material for modification and use.

Unlike the students, the teachers did not modify any of the materials. After viewing the student products, Ruby reflected on the differences between the way the students utilized their provided materials versus the teachers' use of them. She stated that where the students spent time talking about supplies, the teachers used coffee filters right away. She determined this was due to the lack of prior knowledge on filtration system construction for the students (memo). Rather than experimenting with less familiar materials (i.e. Buchner funnels, disassembled fish tank filter components), the teachers used materials such as coffee filters, water bottles, gravel, sand, and strainers to construct science-in-a-bottle filtration systems. The teachers did not see the materials as novel and went directly to materials they knew would accomplish the task rather than experiment with the possibilities.

Amanda observed the lack of pumps present during the teacher models, "I didn't notice if anyone in here used a pump, but a lot of students used them. Maybe they wanted to figure them out" (memo). Instead of the pumps, the teachers used gravitational force to move the water. While the teachers did not compare the advantages of the electric pumps, gravity was presented as a component of a wetland. It is unclear if mimicking this feature of wetlands was intentional, as only one group stated in their presentation that they were "mimicking natural processes."

An overarching concern in resource management was time management. For teachers who have a designated amount time each class period, thinking about how much time students would need helped dictate the selection of materials. The teachers discussed that materials that are easily accessible and manageable were important considerations for the filtration designs when thinking about incorporating such tasks in their own classrooms. When it was time to debrief about the week, Joe stated, "We [teachers] are so used to 43 minutes to put this together, get results, clean up and get to next group."

Attention to Content and the Process of Engineering Design

As the week progressed, researchers observed that teachers were paying attention to pedagogical understanding versus content understanding (like the students). The content goals of the PD included biochemistry of water quality issues, biomimicry, and engineering design. The teachers' lack of content focus became apparent during the final presentations on the last day of the PD. The engineering design task included two content related criteria. The system was to address a clearly defined water quality issue and to be inspired by biological systems.

Teachers were given the same instructions and expectations as the students for presenting their final product. Out of four presentations, one group did not provide any information as to which specific water quality issue their prototype addressed. Instead, they presented a sales pitch for their final presentation, seeming to gloss over the results of their trials and tests. A second group indirectly stated how the prototype will change the water quality in time. A third group presented at length how they hoped to both raise and lower the pH. A common source of confusion surrounding the study of pH related to the fact that a lower pH equals a more acidic substance. So, as the group attempted to lower the acidity of the water, they really aimed to raise the pH. At least one member of the group did not understand this distinction and created confusion during the presentation. The fourth group specifically stated what effect their prototype had on the water quality.

Following the presentations, Joe noted that the students came closer to biomimicry than the adults and Sarah added that the adults focused on making the water drinkable and not biomimicry since people "wouldn't drink out of wetlands." This focus may have prevented the teachers from looking at the task as the students did. Joe noted that the teachers were focused on the time limits, rather than the experience. Where the students looked at the task as "Hey, that's cool," the teachers approached it as "How could we use it" (Sally).

Regarding the practices of engineering design, Sarah pointed out "Their (the students') set ups were more advanced." When asked if she meant more advanced or more complicated, she clarified, "More advanced." In general, the teachers saw the student designs as better responding to the engineering design task. Only one of the teacher groups spent time optimizing their design solution compared to the students who disassembled and reassembled their prototypes multiple times. One teacher group made several changes to their design and their final presentation relied on significant upgrades to their original prototype. This understanding that the process of engineering design requires the team to constantly reevaluate available designs to identify the best solution was not demonstrated by any of the other groups. When asked how they would incorporate what they learned from the week into their own classrooms, Sarah replied, "We would incorporate a budget to limit waste." Sarah's response and the group consensus further illustrates a focus on the pedagogical implications included in management of resources rather than an understanding of the process of engineering design.

Discussion

While the teachers participating in this study are not necessarily beginning or developing teachers, they were novice to the process of engineering design. Yet, current shifts in the expectations described in the NGSS (NGSS Lead States, 2013) set the expectation for the incorporation of more engineering experiences within education. Despite this national push, engineering is not predominately featured in the state standards of the teachers at the time of this study. Until the process of engineering design becomes part of the instructional process, teachers will continue to hesitantly navigate the difficult inclusion of engineering processes within science content.

When planning and implementing professional development, it is important to remember that even though teachers may be ready to learn, teachers have trouble staying in the role of learner (Cunningham & Carlsen, 2014). The teachers' focus on resource management and pedagogy more so than the content is understandable as they try to apply these unfamiliar engineering practices to the realities of their classrooms. By filtering much of the science content out of their presentations and in some cases demonstrating a clear lack of understanding of the concept of pH, the teachers did not demonstrate understanding engineering design or issues surrounding water quality. This minimizes the chance that the teachers would link this process to an enrichment of their students' conceptualization of science content and the ability to apply it in problem solving situations. Additionally, this phenomenon demonstrates the challenge of content-integrated engineering practices within the science classroom. As the teachers themselves struggled to keep the content integrated within the novelty of the engineering task, they may face difficulty in their own classrooms in future engineering task planning and implementation.

To address the teachers' difficulty with the conflicting roles of teacher and learner, Cunningham and Carlsen (2014) suggest providing teachers with windows of time dedicated to their implementation concerns. This allows PD providers the opportunity to contrast those windows with their experiences as a learner of engineering design and its content applications. By doing so, PD providers create a concrete way for teachers to facilitate student-centered/inquiry-based teaching within the constraints and demands of a science period. Given this complexity, a single exposure to engineering practices is not enough. These single exposures make the pedagogical moments difficult to connect beyond the professional development to the classroom.

Yet, planning applicable PD can only get us so far. Unless PD developers can find a way to help teachers explore beyond their reliance on the familiar, teachers will struggle to facilitate and guide their own students through engineering practices upon returning to their classrooms. In the end, it is not the product/solution (like the teachers in this study thought) but the journey (like the students experienced prior) that is key to understanding engineering design.

Without follow-up interviews, it is difficult to discern if the teachers gravitated to known, readily available, cheap supplies (for example small water bottles and coffee filters) solely due to time and budget concerns. The use of coffee filters made cleanup easy as did the use of the water bottles. Water bottles are cheap materials for teachers to acquire. Even though the teachers noted the students' use of plastic bins and water pumps, it is possible that the teachers saw these materials as beyond the budget of their classroom supplies. As districts expect teachers to incorporate new unique solutions (engineering) into their classrooms, the science supply budget does not increase. With limited supplies, teachers may adopt a scarcity mentality and gather what is readily available to use. Classroom management styles may also have come into play. By limiting supplies to what could easily be accessed or replenished, teachers limit potential resource management issues. Instead of dividing attention between passing out supplies, guiding students through the engineering process, and supervising, teachers only need to focus on the latter two.

Limitations of the Study

As a single case study, the findings of this research cannot be extended as generalizations beyond the setting of this professional development and included teacher participants. It should also be noted that the aim of the PD was not necessarily to improve the engineering teaching practices of the participants. Rather the focus was to continue to expose participants to innovations in science teaching and help to facilitate an overall improvement of pedagogy, content understanding, and confidence in science teaching within the context of environmental science with a focus on water by participating as learners in the engineering design task. Finally, there was little opportunity for member-checking beyond the noted conversations between the PD providers and the participants.

Recommendations for Future Research

This small case study leads to several future research questions and possibilities. Due to the teachers' comments and interest regarding the student developed prototypes, it may be beneficial to investigate how combining the teacher task with a student task can help inspire teachers to reach beyond what is known. In what ways does engaging in an engineering design task with students influence the ways in which practicing teachers approach the process? Second, how will an explicit focus on integrating engineering practices into the current pedagogical paradigm demands of teachers (such as state testing and/or student-centered/inquiry-based instruction) impact the ways teachers engage with an engineering design task or instructional plan? Finally, as science teacher educators, we must continue to contribute to the discussion regarding the future of science education. What role does engineering design play in light of the demands on science teachers and science learners and how better can we prepare pre- and in-service educators to respond to those demands?

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Influence of Science Experiences on Preservice Elementary Teachers' Beliefs

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ABSTRACT

The purpose of this mixed-methods research was to investigate changes in preservice elementary teachers' science teaching beliefs and explain how these beliefs influence the way these teachers interpret their science teaching and learning experiences. Supported by the theoretical underpinnings of teacher beliefs and drawings as a tool to investigate teacher beliefs, this research utilized qualitative (written science autobiographies and reflections) and quantitative (Draw-a-Science-Teacher-Test-Checklist as a pre and post measure) data collection techniques. A total of 55 preservice elementary teachers participated from two public universities located in the United States and Canada. Quantitative analysis revealed positive shifts in science teaching beliefs of preservice elementary teachers largely in two ways: A small shift representing small positive difference or a large shift representing large positive difference between the pre- to post-course DASTT-C scores. Qualitative data analysis for the two sub-groups of participants (small shift and large shift) provided evidence that preservice teachers' beliefs were linked to their personal histories and were influenced by their prior science experiences. Preservice teachers' beliefs and their self-images changed as they participated in the field teaching experiences in elementary classrooms and engaged with elementary learners, during the science methods course. Implications for preservice teacher education programs, science teacher education, and research are included.

Keywords: Draw-A-Science Teacher Test-Checklist (DASTT-C), preservice teacher education, science methods courses, science teacher beliefs

Introduction

Science education reforms across the globe strive to achieve high-quality elementary science teaching (Australian Curriculum, 2015; National Curriculum in England, 2015; Newfoundland & Labrador, Department of Education, 2016; NGSS Lead States, 2013). And, teachers play a critical role (Battista, 1994) as "the decisive component" in implementing any science education reform (Bybee, 2014, p. 144). Despite the calls and systemic reform initiatives to improve science teaching in elementary classrooms (AAAS, 1993; NRC, 2012; No Child Left Behind, 2000; van Driel, Beijaard & Verloop, 2001), anecdotal evidence from the recent surveys in the United States and Canada suggest that fewer elementary teachers felt prepared to teach science (Banilower et al., 2013; Rowell & Ebbers, 2004; Trygstad, Smith, Banilower, & Nelson, 2013), and sometimes tend to avoid teaching science altogether (Appleton & Kindt, 2002). Past research highlights several factors related to elementary teachers' preparedness to teach science such as limited science content knowledge, confidence to teach science, and less positive attitudes and beliefs about science teaching (Bianchini & Colburn, 2000;

Gunning & Mensah, 2011; Howes, 2002; Murphy, Neil & Beggs, 2007; Rice, 2005; Taylor & Corrigan, 2005).

Science teaching beliefs have a strong impact on teachers' practices (Pajares, 1992; Richardson, 1996), and have become an important area of research within the last few decades. Research has shown that teachers' science teaching beliefs influence (a) their instructional decisions and learning (Rubie-Davies, Flint, & McDonald, 2012), (b) implementation of content and/or curricula in a classroom (Luft, 1999; Roehrig, Kruse, & Kern, 2007), and (c) reasons to engage in certain type of science teaching practices, such as inquiry (Lotter et al., 2007; Roehrig et al., 2007). Science teaching beliefs center at teachers' views about disciplinary knowledge on how children learn, specifically, how they "make sense of science concepts," guiding their goals "to promote students' deep thinking, rather than students memorizing factual and discrete information" (Crawford, 2007, p. 17). However, there is an evidence that beliefs and practices are not essentially consistent because teacher negotiates their beliefs differently in changing contexts, which makes this interaction complex and context-dependent. (Kang & Wallace, 2005; Savasci & Berlin, 2012). Science teaching beliefs are "personal construction" of ideas, and therefore, the goal of teacher preparation programs is to promote positive changes in teachers' beliefs about science teaching (Jones & Leagon, 2013). Therefore, science teacher educators "need to find new and different ways to challenge preservice teachers to move towards the formation of reform-based beliefs" (Fletcher & Luft, 2011, p. 1144).

Preservice teachers enter teacher education programs with a set of beliefs regarding science teaching that impact their views of self as a science teacher and science teacher self-image (Menon, 2016; Richardson, 2003). Researchers argue that teacher beliefs and self-images are re-shaped within the teacher preparation programs that are carried to future classrooms (Menon, 2016; Bautista, 2011; Gunning & Mensah, 2011; Hancock & Gallard, 2004). There is enough evidence that teachers restructure their science teaching beliefs during science methods courses (Ambusaidi & Al-Balushi, 2012; Hancock & Gallard, 2004; Minogue, 2010; Pilitsis & Duncan, 2012). However, some evidence shows regression to these changed beliefs by shifting back to beliefs that teachers brought to the course (Fletcher & Luft, 2011). This evidence has emphasized the need to study this *change* to explore how teachers' initial beliefs, shaped by their K-12 science experiences, called "insider effect" (Pajares, 1992), further influence their beliefs in science education programs. Understanding how newer experiences within the science methods courses influence one's 'belief-system' can help teacher educators provide more meaningful and appropriate support during the science methods course to enhance the stability of this change.

The present study not only examines the change in science teaching beliefs by identifying the science teaching beliefs that preservice elementary teachers (PETs) brought to their science methods course but the science teaching beliefs they left the course. This research also quantifies this change by determining the amount of shift in PETs' science teaching beliefs during the science methods course and investigates two distinct groups of PETs with a small and a large shift in their science teaching belief to examine how these two groups interpret their science teaching and learning experiences. Specifically, the following research questions are part of this investigation: (1) How do preservice elementary teachers' prior science experiences influence their initial science teaching beliefs? (2) How do preservice elementary teachers' experiences within the science methods course influence their science teaching beliefs?

Theoretical Underpinnings and Background Literature

This study draws on two theoretical underpinnings (a) teacher beliefs about teaching and learning, and (b) drawing in science education. Below is the description of these theoretical perspectives and their interpretation for the purposes of this study.

Teacher Beliefs about Science Teaching and Learning

Teacher beliefs that relate to teachers' motivation and performance have been defined and conceptualized in many different ways by researchers in the field. Pajares (1992) defined teacher beliefs as "individual's judgment of the truth or falsity of a proposition, a judgment that can only be inferred from a collective understanding of what human beings say, intend, and do" (p. 316). According to Nespor (1987), beliefs are highly influenced by prior experiences and these "episodic memory of prior events" influence teacher practices (p. 17). With regard to the teaching profession, several researchers relate beliefs systems to teacher behavior and instructional decisions (Nespor, 1987; Pajares, 1992). Others also assert that beliefs held by teachers determine decisions regarding the adoption of curriculum reforms and new research-based strategies (van Driel, Bulte, & Verloop, 2007). There is a consensus in the literature that understanding teacher beliefs is crucial to improving classroom practices because these beliefs act as filters through which teachers process relevant information and interpret new knowledge related to teaching (Kagan, 1992; Putnam & Burko, 1997).

Teachers' beliefs have been the topic of great interest in the science education research community as they are highly influential in teachers' classroom practices. Some researchers argue that beliefs that preservice teachers hold at the time they begin their teacher preparation coursework are difficult to amend (Kagan, 1992; Pajaras, 1992). However, others argue that experiences within the teacher preparation programs may help shape beliefs regarding their ability to teach science (Gencer & Cakiroglu, 2007; Mulholland & Wallace, 2001). Past research shows that the belief system is adaptive in nature, and experiences have the potential to refine beliefs that preservice teachers hold at the time of entering teacher preparation program (Bursal, 2010; Yilmaz-Tuzun, 2008). Empirical studies have documented that hands-on learning experiences, along with instructor modeling of appropriate teaching practices positively impact preservice teachers' self-efficacy beliefs (Menon, 2016; Menon, 2018; Bautista, 2011; Palmer, 2006). Other studies document that science methods courses provide a variety of experiences to enhance preservice teachers' self-efficacy beliefs such as hands-on investigations, designing science lesson plans, watching videos of exemplary science teaching, and holding discussions of different aspects of teaching (Bautista, 2011; Gunning & Mensah, 2011; Mulholland & Wallace, 2001).

Changes in Teachers' Beliefs

Research has established that preservice teachers' science teaching beliefs change during teacher education program (Menon, 2016; Bautista, 2011; Gunning & Mensah, 2011; Hancock & Gallard, 2004), particularly during science methods course (Ambusaidi & Al-Balushi, 2012; Hancock & Gallard, 2004; Minogue, 2010; Pilitsis & Duncan, 2012). And, teachers' previous experiences related to science learning and teaching are considered to influence this change process (Gunstone et al. 1993; McDiarmid et al. 1989; Olson & Appleton, 2006), which is referred to as an "insider effect" by Pajares (1992). However, the role of this insider effect has not been an explicit focus of research on science teachers' beliefs. In this current research, we conjecture that PETs' previous belief systems about teaching science could be shaped through the science methods coursework; however, this change may not be consistent. We investigate the group of PETs with varied shifts in their science teaching beliefs and study how they interpret their prior science learning experiences. We further investigate whether and how PETs' negotiate their science teaching beliefs in the context of new experiences gained in the science methods course.

Studying Teachers' Beliefs

To uncover preservice teachers' complex set of beliefs about science teaching, researchers have utilized a variety of tools and methods including interviews (Brown & McNamara, 2011; Furlong, 2013; Luft & Roehrig, 2007), questionnaires (Avalos & De Los Rios, 2013; Hong, 2010), focus groups (Avalos & De Los Rios, 2013), and drawings as preservice teachers' images of self as science teachers (Markic & Eilks, 2012; 2015; Markic et al. 2016; Thomas, Pedersen, & Finson, 2001). Drawings have been considered as an important tool for preservice teachers to reflect on their views on how they represent themselves as a teacher of science, within a classroom, and their students as science learners. One of the commonly used drawing tools is the Draw-A Science-Teacher-Test-Checklist (DASTT-C) developed by Thomas, Pedersen, and Finson (2001). Past studies utilized pre and post-test design implementing the DASTT-C tool to preservice teachers at the beginning and end of an intervention or a semester-long course (Markic et al. 2016; Markic & Eilks, 2012; 2013; 2015). It has been established that science methods courses support the changes in preservice teachers' beliefs, as evident from their drawings (Markic et al. 2016; Markic & Eilks, 2012; 2013; 2015).

Drawings in Science Teacher Education

Studies suggest that preservice teachers' beliefs regarding science teaching shape their perceptions of self as science teachers (Menon, 2016, 2020). Literature posits that preservice teachers' drawings of themselves as science teachers are a valuable tool to reveal their perceptions of science teaching as well as their self-image as science teachers (Akkus, 2013; Finson, 2001; Minogue, 2010). To illustrate, researchers suggest that drawings of self as science teachers provide information about mental models capturing the ways preservice teachers may identify themselves as teachers of science and their students as learners of science. One of the drawing tools widely used to provide insights on preservice teachers' views of teaching is the Draw-A-Science Teacher Test Checklist (DASTT-C), developed by Thomas, Pederson, and Finson (2001). This tool is an extension of the previous work where Finson, Beaver, and Crammond (1995) developed the Draw-A-Scientist-Test Checklist (DAST-C) based on the Draw-A-Scientist-Test (DAST) developed by Chambers (1983). The tool allows preservice teachers' to think about themselves as science teachers and how do they want to represent themselves in a classroom. It also permits preservice teachers to think about their students and how they perceive overall science instruction for their classrooms. According to Thomas et al. (2001), DASTT-C allows preservice teachers to "(a) picture themselves as elementary science teachers, (b) place themselves along a teaching theory continuum, and (c) consider the ways in which they developed their own science teaching beliefs" (p. 298).

Several studies use DASTT-C as a tool to understand preservice teachers' science teaching beliefs on a continuum ranging from traditional views of teaching (teacher-centered) to student-centered views that are aligned with inquiry-based teaching (student-centered instruction). In general, this tool has been used as a pre and post-test to understand the self-image before and after the intervention. A majority of studies document that preservice teachers' initial science teaching beliefs are teacher-centered at the time they enter the teacher preparation program, and there is a lack of focus on how teacher actions impact positive student learning (Markic & Eilks, 2013; Thomas & Pederson, 2003). Buldur (2017) found that preservice teachers' beliefs about science teaching changed from the traditional to student-centered beliefs after their exposure in a science methods course. Other studies suggest that preservice teachers held traditional views of teaching as depicted by their drawings at the beginning of the science methods course (Ambusaidi & Al-Balushi, 2012; Finson, 2001; Minogue, 2010). In a study conducted by Ambusaidi and Al-balushi (2011), there were significant shifts in preservice teachers' beliefs from teacher-centered to the student-centered view of instruction after the first science methods course; however, the second methods course and teaching practicum did not bring any further change in their beliefs. For the purposes of this study, we adopted the DASTT-C tool to investigate the change in PETs' science teaching beliefs during a science methods course and examine the role of prior experiences in this process.

Methodology

Research Design

This mixed methods research integrates quantitative [quan] and qualitative [QUAL] data by utilizing a triangulation convergent design [quan +QUAL → comparison of quan and QUAL results] (Creswell & Plano Clark, 2011). Mixed methods research "focuses on collecting, analyzing, and mixing both quantitative and qualitative data" and uses them in combination to provide a better understanding of the research problem (Creswell & Plano Clark, 2011, p. 5). In this design, we collected, analyzed, and mixed both quantitative (DASTT-C scores) and qualitative (experiences described in science autobiographies and reflections) data in the context of a science methods course, however, qualitative data weigh more than the quantitative data . This mixed-methods approach provided a better understanding of the research problem that is understanding a connection between PETs' science teaching beliefs and their science learning and teaching experiences before and after the course. The quantitative data were collected using DASTT-C as a pre and post measure. The qualitative data were collected through written science autobiographies and reflections, classroom observations, and artifacts. While the quantitative tool was useful to provide information regarding preservice teachers' beliefs through their drawings, qualitative data provided a deeper understanding of how preservice teachers' drawings were related to their science learning and teaching experiences before and after their participation in the course. Triangulation of results across multiple data sources is a foundational concept that provides a justification for using mixed method research through enhanced validity (Green, 2007). It emphasizes rigor through the conjunction of results from the qualitative and quantitative methods. Therefore, both quantitative and qualitative data were compared and contrasted to explain the research problem that is a connection between PETs' science teaching beliefs and their experiences with science and science teaching before and during the course.

Research Context

The study is part of a research project conducted at two public universities in the Atlantic Region, in the context of two science education courses, one in the United States and the other in Canada. At the mid-Atlantic public university in the United States (U.S.), the science education course was offered in the Spring and Fall semester 2017, and the average enrollment in the course ranges from 15-18 PETs. At the Canadian university, the science education course was offered in Spring 2017 and a typical enrollment in the course ranges from 20-25 PETs. Both the courses were 3 credit hours. However, the course span for two courses varied regarding the time for weekly class meetings and the number of weeks. Table 1 describes the common course components.

Table 1
Science Methods Course Experiences and Activities

Course Activities	Learning Experiences
Hands-on science (science and engineering practices)	Preservice teachers participate in several hands-on inquiry activities designed to model reform-based science and engineering practices. The intent of hands-on science activities was to provide opportunities for preservice teachers to engage in science and engineering practices such as 'planning and carrying out investigations, 'asking relevant questions and defining problems.'
Planning science lessons	Preservice teachers plan and design science lesson plans for teaching in an elementary classroom. They receive feedback from peers and the course instructor. Through the experience, preservice teachers develop the skills of planning effective science lessons based on science practices. This is an iterative process, which requires them to make improvements to their lesson based on the feedback from the course instructor.
Field-based teaching	Preservice teachers teach their science lessons in elementary classrooms. Teaching science in elementary classrooms provide preservice teachers first-hand teaching experiences for them to practice what they learned in the course. The intent is that through teaching lessons in real classrooms, they will develop confidence in science teaching.
Reflective Practices	Reflective practices were incorporated throughout the course to help preservice elementary teachers to confront, challenge, and shape their science teaching beliefs. At the beginning of the course, PETs reflected on their K-12 and college science experiences that might have shaped their attitudes and beliefs about science and science teaching. Sharing these experiences with peers, help PETs to judge the science teaching experiences that help learning science. During the course, PETs were provided opportunities to reflect on the course experiences to help them gain a new understanding of science teaching, using these experiences to help science learning of their future students and rethink and reshape their science teaching beliefs. As a part of field-based teaching experiences, PET reflect on their teaching of science lessons and their students' learning to understand what works in a real classroom to strengthen research-based and reformed base science teaching beliefs

Participants

A total of 55 PETs participated in this research. At the public university in the United States, 42 PETs enrolled in the two sections of the course offerings in the Spring and Fall semester, out of which 36 volunteered to participate in the study. A majority of the participants were females (one male and 35 females). The participants were between the age group of 20- 23 years with a few exceptions (three participants of age 25, and one participant was of age 33 years). A majority of them were Caucasian, with a few exceptions (four Asian, seven Hispanic, one Ethiopian and one of Native American origin). At the Canadian University, 27 PETs enrolled in the course, out of which 19 volunteered to participate in the study. A majority of them were females (18 females and one male).

The participants were between the age group of 20-25 years with one exception, who was 30 years old. All participants were of white Canadian ethnicity. They all had completed an undergraduate degree, including nine credit hour courses in three science areas or two specially designed science courses for elementary teachers, before entering their after-degree Bachelor of Education program.

Data Sources

Data collection procedures included both qualitative and quantitative sources of data. The qualitative sources of data included participants' written science autobiographies, individual reflection papers, researchers' field-notes on student-teaching sessions, and artifacts. Each data collection source is described in detail below. The quantitative sources of data included pre and post-drawings, collected through the Draw-A-Science-Teacher Test Checklist (DASTT-C) instrument, developed by Thomas et al. (2001) and modified by Markic & Eilks (2012), at the beginning of the semester and towards the end of the semester.

1. **Science autobiography.** Science autobiographies have been considered as a useful tool to reflect and narrate their past experiences (positive and negative) with science and to reveal their teacher self (Ellsworth & Buss, 2000). This research used written science autobiographies of participants as a source of qualitative data to access PETs' prior experiences with science learning and teaching. Participants' written science autobiographies ranged between 1200 - 1500 words and contained a description of events and incidents related to prior science learning and teaching.

2. **Reflections.** Engaging PETs in the process of reflecting on their teaching experiences allow them to discover the strategies that work in the classroom and help them identify their areas for improvement (Davis, 2006; Lee, 2005). This research used written reflection papers by the participants as a source of qualitative data to analyze their experiences with planning and teaching a science lesson in an elementary classroom. Participants' written reflections consisted of 1500-1800 words and contained their reflections about what went well, what did not go well in their science lesson, and what changes they would like to make if teaching the same lesson in the future. Participants' written reflections helped us in interpreting their beliefs about science learning and teaching, which have the potential to influence their future science teaching.

3. **Draw-A-Science-Teacher-Test Checklist (DASTT-C)**. A drawing tool, Draw-A-Science-Teacher-Test Checklist (DASTT-C) developed by Thomas, Pedersen, and Finson (2001) and modified by Markic, Eilks, and Valanides (2008) was used in this research study to make explicit participants' mental representations of science teaching before and after the course. The central idea of DASTT-C was to prompt participants to draw themselves and their students engaged in a science teaching act/situation (see Appendix A). In addition to drawings, we further asked them to describe their illustration of the teaching act/situation as it relates to teacher's and students' activities. Analysis of participants' pre and post-drawings helped us interpret their science teaching beliefs before and after the course.

Data Analysis

Below, we describe the quantitative and qualitative data analysis techniques. The qualitative data were analyzed first, followed by the analysis of the quantitative data.

Qualitative Data Analysis

The qualitative data were analyzed in three stages. In the first stage, open coding techniques were used that involved reading the written science autobiographies and reflection papers multiple times to identify common events or ideas described by the participants. To begin with, both researchers independently coded one autobiography and one reflection paper. The researchers discussed and compared initial codes, and any discrepancies were resolved through discussion. Then, both researchers coded all of the autobiographies and reflection papers based on their initial agreement on codes. At the second stage, axial coding was employed to assemble initial codes into categories and subcategories. A coding scheme was generated where categories and subcategories were rearranged in three broader themes, namely: Teacher, Student, and Environment.

Table 2
Sample Coding Scheme for Science Autobiographies and Reflections

Categories		Description	Codes	Sample Quote
Autobiographies	Teacher	Prior experiences with science teachers	Struggle with science, discontentment with the science teacher	I felt she didn't really understand me. Maybe she expected too much, or I didn't grasp the material very well. I struggled to try to remember detail by detail the definitions of the part of the eye and how light traveled. I thought I had to get it exact by the book to prove I knew the content
	Student	Prior experiences as a science learner	Lack of confidence in science	I lost my confidence in my own ability to master the concepts being taught, and it became a challenge to get good marks. I began to always second guess myself, thus spending more time trying to learn than actual learning.
	Environment	The learning environment in a previous science course	Memorization, note-taking	It seemed that science in my senior year was more about memorization than about really knowing how something works or how it relates to our understanding of the world. I recall a lot of nights trying to memorize definitions and long answer questions, trying not to leave out a word.
Reflections	Teacher	Experiences of teaching a science lesson	Lesson Planning (effective science lesson)	The skill of effective lesson planning was necessary to ensure that the children were engaged in the lesson during our time at the school.
	Student	Experiences of science learners while teaching	Student Engagement	One of the reasons that I believe the lesson was successful is because the students were engaged throughout the entire lesson, which shows that they found the lesson and activities interesting.
	Environment	The learning environment created while teaching science	Collaborative learning	To allow students to explore the topic, we put them into groups asked them to identify as many animals as they could in each of the four habitats. We then followed up with a group discussion on the different animals identified as well as why the students classified them under each category.

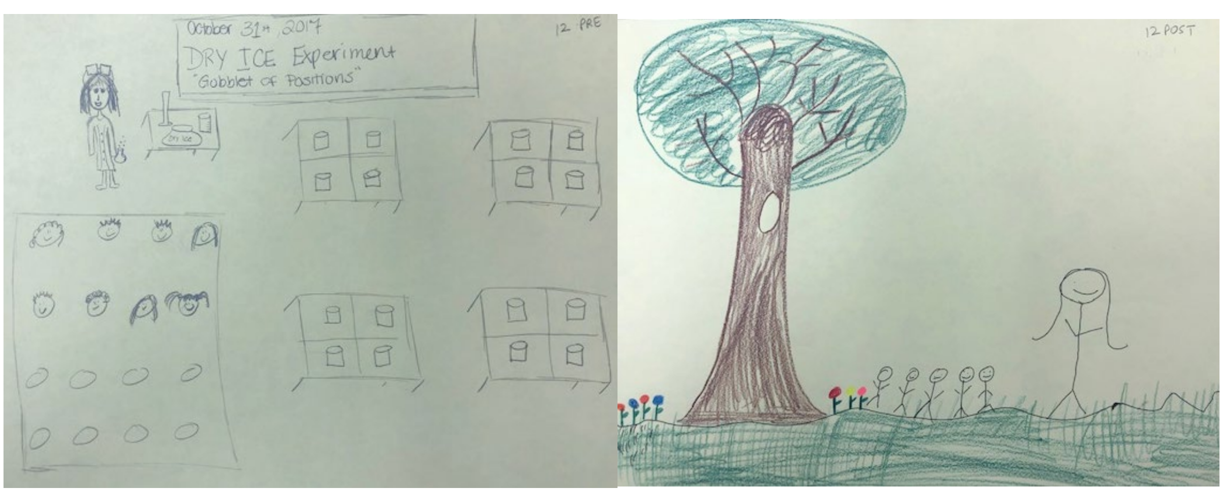
The peer-debriefing and triangulation across multiple sources contributed towards the trustworthiness. We purposefully aimed for evidence that supports or refutes themes that emerged from the various data sources, and this process enabled the triangulation of the findings. Thus, triangulation provided a thorough and comprehensive understanding of the complex phenomena under investigation, particularly regarding the connections between self-images and their science learning and teaching experiences.

Quantitative Analysis

The analysis of the drawings from the DASTT-C tool was based on the checklist suggested by Thomas et al. (2001); the score for each drawing was calculated based on the presence or absence of these 13 elements (see Appendix B).

Below, we present an example of our analysis of the pre and post-drawing of a participant (Participant 12). The participant received a score of 11 points for the pre-drawing (see Figure 1a). This score represents teacher-centered beliefs held by the participant. A closer examination of the drawing shows a teacher demonstrating a science experiment/activity and using a whiteboard with a written caption of the experiment (teacher activity). The teacher is positioned at the center of the class with a somewhat erect posture (teacher position). The students are seated in rows in front of the teacher (student position), and they are listening to or watching the teacher (student activity). The student desks are arranged in a traditional pattern, while the teacher's desk is located in front of the class. Further, the symbols of science (equipment) can be seen on the teacher's desk, and symbols of teaching (whiteboard) can be seen in front of the classroom (Environment). The post-drawing received a score of 1 representing student-centered beliefs regarding science teaching (see Figure 1b). A closer look at the post-drawing shows that the class is being held outside, where students are able to explore the natural environment. Here, the students' group is taking the lead looking into the plants and trees while the teacher is at a distance behind the students (teacher position). Students are sitting on the ground as a group exploring and appear to have fun with the activity. The learning environment is non-traditional with no classroom seating pattern, and no symbols of science and teaching can be seen.

Figure 1
Participant 12 (a) Pre-Drawing (DASTT-C Score 11) and (b) Post-Drawing (DASTT-C Score 1)



Inter-Rater Reliability

Each researcher independently coded four drawings of the same participants that were randomly selected from the sample. The inter-rater reliability was calculated using Cohen's Kappa for a total of 52 entries for the 4 participants (13 elements per participant data). There was less than 50% agreement between the two coders. One of the problems was how each coder interpreted each element within the three dimensions. For instance, the teacher's posture or student activities were at times unclear in drawings. After a thorough discussion of the three elements, eight drawings (15% of the data) were randomly picked and independently coded by each researcher. The value of Cohen's Kappa was found to be 0.923 with $p<0.001$, indicating a strong agreement between the two coders (Hallgren, 2012).

DASTT-C Scoring Issues

In addition to the scoring issues due to subjectivity, as described above, other issues were identified. According to Thomas et al. (2001), the score ranging between 7 and 13 represents teacher-centered beliefs, whereas the score between 0 and 4 represents student-centered beliefs. What it means is that the two participants with a score of 13 and 7 in their drawings respectively, are both in the category of teacher-centered beliefs. Similarly, a score of 0 and 4 for any two distinct participants' drawings are in the category of student-centered beliefs. Our challenge was to distinguish between the participants falling into similar categories, considering the scoring scheme is a spectrum. Therefore, we decided that instead of distinguishing PETs based on teacher-centered and student-centered beliefs only (as per the challenge described above), we created categories 'small' and 'large' shifts in science teaching beliefs. The small shift represents small positive differences from pre to post-DASTT-C score, where PETs entered the science methods course with somewhat student-centered beliefs and improved on these during the course. The large shift represents large differences from pre to post-DASTT-C score, where PETs entered the science methods course with teacher-centered beliefs and the beliefs changed to somewhat student-centered beliefs.

In addition, Thomas et al. (2001) considered a score of 5 or 6 as indecisive, which we found in a few cases. However, in most cases, invalid score of 5 or 6 was for both pre- and post-drawings. We decided to not focus on these cases in this study, due to a relatively small number of invalid cases.

Findings

We present the quantitative analysis of the DASTT-C scores followed by the qualitative trends from science autobiographies and reflection. First, we present the shift in PETs' science teaching beliefs from the beginning to the end of the science methods course based on their DASTT-C scores at the beginning and the end of the course. Then, we present examples from the large shift and small shift groups to reveal how PETs from these two groups interpret their science teaching and learning experiences.

The Shift in PETs' Science Teaching Beliefs

We found positive shifts in PETs' drawings with more student-centered beliefs from pre to post-test; however, the amount of the shift varied on the scale of 0-13. Table 3 presents a shift in PETs' science teaching beliefs based on their pre and post overall DASTT-C score.

Table 3

Change in Science Teaching Beliefs Based on Pre to Post DASTT-C Scores

Change in Science Teaching Belief		DASTT-C Score Range
Large-shift	32	9-13 pre score & 0-4 post score
Small-shift	17	6-4 pre score & 0-3 in post score
No-shift	1	7 pre score & 7 post score
Invalid cases	5	Pre and post scores ranged between 5 to 6, considered as indecisive (Thomas et al. 2001)
Total	55	

Examples of a Small and a Large Shift in Science Teaching Beliefs

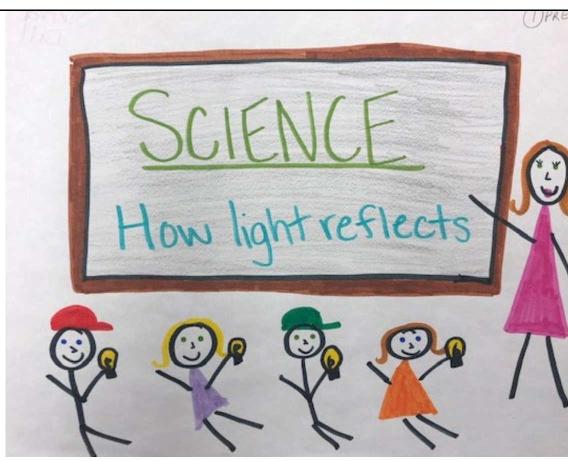
In this section, we present two examples that highlight a large shift (Amanda and Sarah), one from the USA and one from Canada, and two examples of a small shift (Lucy and Karen), one from the USA and one from Canada, in these PETs' beliefs regarding science teaching and learning using the pre and post-DASTT-C scores. Then, we present the themes from analysis of these participants' written science autobiographies and reflections representing similarities and differences in their interpretations of prior science experiences and the science methods course experiences influencing their science teaching beliefs.

Figure 2a displays the pre and post-DASTT-C scores of Amanda and Sarah (large shift) and Figure 2b displays the pre and post-DASTT-C scores of Lucy and Karen (small shift), along with the qualitative interpretation of their drawings showing a small and large shift in their science teaching beliefs.

Figure 2a

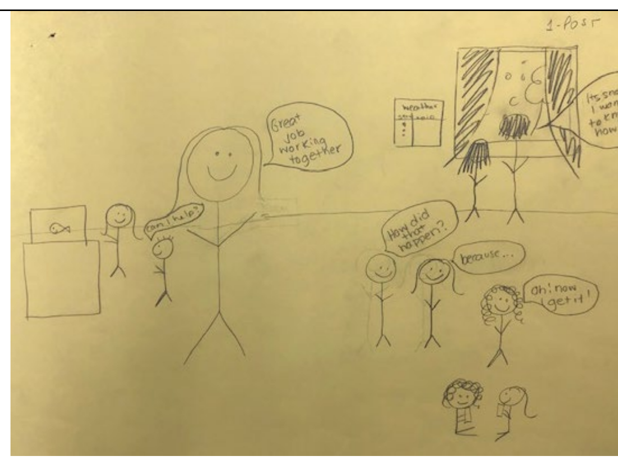
Large Shift Participants' Pre- and Post-Drawings

Amanda pre-drawing



DASTT-C score = 10. The teacher appears to be leading/giving instructions using a whiteboard. The teacher appears to be standing and as a head of the class, and has an erect posture. Students are sitting/standing in front of the teacher and appear to listening/responding to the teacher.

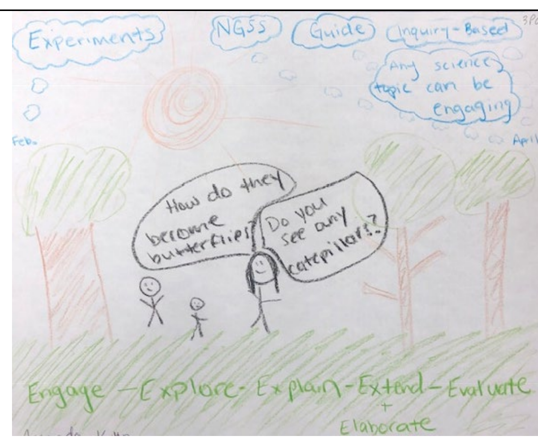
Amanda post-drawing

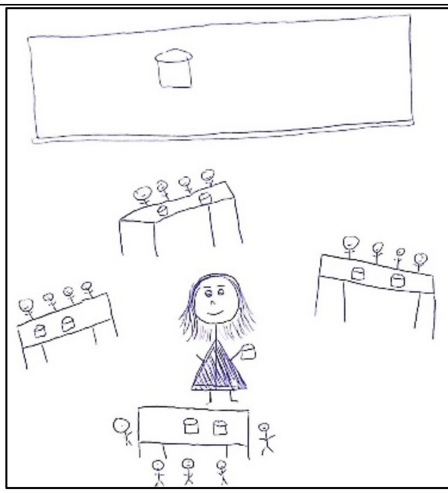
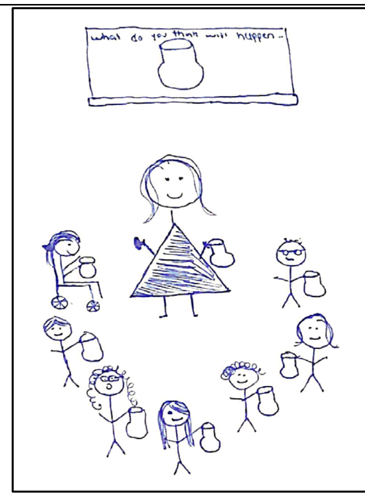


DASTT-C score = 4. The teacher appears to be more of a guide and is positioned in the center of the classroom with students. Student are working in groups and the classroom appears less structured and more inquiry-oriented. The learning environment appears to be less traditional in the post-course drawing.

Sarah pre-drawing	**Sarah post-drawing**
	
DASTT-C score = 12. The teacher is leading/giving instructions using a whiteboard, standing as a head of the class, and appear to have an erect posture. Students are sitting/standing in front of the teacher and appear to be listening to the teacher as she is holding an object and a worksheet in her hand.	**DASTT-C score = 4.** The teacher appears to be asking thought provoking questions to students ("I wonder" questions). The teacher posture is not erect but rather welcoming. Students appear to be involved in a thinking process and sharing ideas. The learning environment appears to be less traditional.

Figure 2b
Small Shift Participants' Pre- and Post-Drawings

Lucy pre-drawing	**Lucy post-drawing**
	
DASTT-C score = 4. The teacher is guiding students to making observations outside the classroom, positioned at a distance from the students and does not appear to have an erect posture. Students appear to be standing on the ground and listening to their teacher. The learning environment is non-traditional with no classroom seating.	**DASTT-C score = 2.** This drawing also shows learning taking place outside the classroom. A major difference is that the teacher is with students as a guide as opposed to be standing at a distance and giving instructions (as in the previous picture). Students are exploring the natural environment. This is not a traditional classroom with no classroom seating pattern.

Karen pre-drawing	**Karen post-drawing**
 **DASTT-C score = 4** The teacher appears to be guiding students to complete an activity, positioned in the center from the students' desks. Students appear to be performing the experiment as their desks as a group, while desks are not arranged in rows. The teacher does not have an erect posture.	 **DASTT-C score = 3.** While the teacher is holding the equipment in her hand; however, it appears that all students are getting equal opportunity to perform the task. The teacher appears to be with the student-group in a circle where students are not seated in a traditional manner. The learning environment is less-traditional and more inclusive (we see a student with special needs sitting on a wheelchair but performing as other students).

Influences on Science Teaching Beliefs

In this section, we describe findings from the qualitative analysis to reveal how prior science experiences and the science methods course experiences influenced PETs' science teaching beliefs. We particularly focused on how participant with small and large shifts in their science teaching beliefs, from the beginning to the end of the semester, interpret their science learning and teaching experiences. First, we present themes from analysis of science autobiographies followed by the analysis of their reflections to represent similarities and differences in their interpretations of prior science experiences and the science methods course experiences influencing their science teaching beliefs.

Prior Science Experiences Influencing Science Teaching Beliefs. Findings in this section are organized under three themes: (a) experiences with science teachers, (b) experiences as science learners, and (c) experiences with the learning environment in prior science courses.

Experiences with Science Teachers. In this section, we present participants' description of their experiences with their prior science teachers and how specific teacher attributes impacted their interest in science. There were noticeable differences between the prior science experiences of participants' who had large shifts in their DASTT-C scores versus those who had small shifts in their DASTT-C pre to post scores. Participants with large shifts often mentioned their distress towards science. In general, two participants, Sarah, and Amanda (large shift) often reported negative experiences with their science teachers. For instance, Sarah reported her teachers from high school science courses as those who "didn't really bring enthusiasm to the class" to help them get excited about the science topic. These experiences seemed to affect participants' confidence in the subject. As Amanda reported, "Those negative experiences affected me by making me not like the topic covered and also decreased my confidence levels in those areas." Conversely, participants, Karen, and Lucy (small shift), who had small shifts in their scores often reported their science teachers as 'great teachers' and used adjectives such as 'enthusiastic' and 'passionate' for their science teachers. These participants reported that their interest in science developed because of their teachers, as Karen mentioned, "having excellent science teachers is a reason why I love science. Throughout my school years, I was fortunate enough to have a number of great teachers, especially in science."

Interestingly, there were differences in the teaching strategies employed by the science teachers in the prior science courses for large versus small shift participants, which impacted their present beliefs about science teaching. For instance, participants who had large shifts in DASTT-C scores reported using worksheets more often. As Sarah mentioned, "I can recall a lot of worksheets and coloring material, I am unable to remember much about the science content." Conversely, Karen, who had a small shift in DASTT-C scores mentioned learning via a variety of strategies employed by her teachers, which sparked her interest in science. She mentioned, "Not only is my science teacher responsible for creating that spark within me, but I also think that my love for science is largely due to the wide variety of activities he made us performed within our class."

E*xperiences as Science Learners.* In this section, participants from the above two groups describe their prior science experiences and how they felt about learning science in their schools and colleges. In general, the prior science learning experiences were mostly positive for participants who had small shifts in their DASTT-C pre to post scores as compared to participants with large shifts in pre to post scores. For the small shift participants, science was relatable for their daily life and part of their daily school routine since elementary grade-level. As Lucy (small shift) wrote, "The science classes that I took in high school increased my interest in understanding how things occur. Science was a part of my daily learning and no matter how long I spent focusing on science I never got tired of it." In contrast, participants who had a large shift in pre and post score mentioned anxiety and pressure when learning science. As Amanda (large shift) mentioned, "I felt so much pressure during lab to not make a mistake." Sarah wrote similar thoughts as she mentioned, "When having to do experiments and record our answers, I had a lot of anxiety over getting the same result as everyone else." Both participants' responses about their experiences as a science learner suggested disappointment with lack of success in learning science content.

Experiences Within the Learning Environment. The learning environment refers to how participants described their science class atmosphere and whether they found the atmosphere conducive towards their learning. The participants with a large shift in their pre to post-DASTT-C scores reported more memorization and learning facts rather than learning through strategies that led to deeper connections with the material. For instance, Sarah (large shift) described the learning environment as "unpleasant because his teaching approach was not very effective and hurtful at times toward the class. It did not create a pleasant atmosphere for learning." Similarly, Amanda (large shift) described prior science learning as "disorganized and straight from the book" or "test-oriented and brutal as unless you had the information memorized like the back of your hand there was no way to succeed." On the contrary, Karen and Lucy (small shift) described their learning environment as having "freedom and independence." Karen elaborated on the positive environment, "I was able to explore through experimentation. I enjoyed doing experiments the most because they were hands-on and it allowed me to apply what I learned in class to the experiment."

Science Methods Course Experiences Influencing Science Teaching Beliefs. The findings have been organized under three themes: (1) experiences as science teachers, (2) experiences with young learners, and (3) experiences in the learning environment participants created for their learners.

Experiences as Science Teachers. In this section, we describe participants' science methods course experiences and how these experiences impacted their confidence in science teaching. Participants from both groups (large and small shift) described their experiences regarding planning and implementing their science lessons in elementary classrooms. Despite having varied prior science experiences, both participant groups described their experiences of using the 5E learning cycle and probing questions to engage students. For example, Sarah (large shift) wrote, "We asked them if they knew how animals protect themselves in their environment and then guided them through an activity using their imagination to pretend they were an animal trying to avoid a predator. We then asked them questions on how they kept themselves hidden, what animal they were, and if they could catch their prey." Similarly, Karen (small shift) said, "We asked questions that encouraged higher level thinking such as, "What do you think would happen if all the trees in a forest were cut down to make room for new buildings?" The participants' views on thought-provoking questioning is interesting as not all participants learned science this way but were willing to include more questioning rather than 'teacher telling' traditional approach.

Both participant groups (small and large shift) felt that the learning cycle approach offered more clarity towards building students' understanding of the science concepts and saw value in teaching this way. While describing their experiences using 5Es in their reflections, we noticed that while the 5E model was an obvious approach to teaching for the participants with small shifts in their DASTT-C scores, it was a reflective approach for participants with large shifts to make that strategy as their choice for their teaching. For example, Sarah (large shift) "thought about reading the book to the students," however, reflecting on the lesson objectives, she changed the lesson plan and decided to use "a more hands-on approach" to engage her science learners. She further described that "the key strategies that guided their group's lessons were constructivism and 5E approach."

The participants' thoughts are interesting considering that participants' with a large shift in their DASTT-C scores did not experience inquiry-based science teaching in their previous science courses. On the other hand, participants with a small shift in their DASTT-C scores integrated hands-on approach seamlessly in their lesson planning and were more confident in doing so for their science lesson. As Lucy (small shift) said, "My group member and I vigorously prepared our lesson plan until we were comfortable and confident with the material we were planning to teach to the children. We followed the 5E model when developing our lesson plan." It is worth noting that the participants with small shift were more exposed to hands-on inquiry-based learning in their previous science courses, as evident from their descriptions in their science autobiographies.

Experiences with Science Learners. In this section, we describe participants' experiences with young learners while reflecting on their science teaching experiences, which revealed that both participant groups (with a large and small shift in their pre-post DASTT-C scores) were able to engage their learners successfully. Witnessing their students' interest in their science lessons enhanced participants' confidence in science teaching. For example, Amanda (large shift) described, "I feel that the students responded well to the lesson and to us. They were comfortable in asking us questions and interested in learning what we were teaching." Similarly, Karen (small shift) mentioned, "They were much more engaged than we had anticipated and it filled me with encouragement and pride when teaching the lesson." Lucy's (small shift) response echoed this tendency: "The students had a positive response to the lesson, and they were very interested and engaged throughout the entire thing."

Both participant groups shared their success with student engagement, however, there were few differences in terms of the challenges they faced. In general, the participants with small shifts in their pre to post-DASTT-C scores were more confident in their ability to engage young learners and described their positive experiences with their students' learning as a result of their field teaching. Conversely, the participants who had a large shift in their pre to post-DASTT-C scores, who earlier had negative science experiences as science learners, shared challenges that they faced helping their students. For example, Sarah (large shift) wrote, "I think that the most commonplace that our students got stuck on was the data chart. I think that even though we explained how to record the answers and where it would all go on the sheet, they still had difficulty looking up and down the column and across the row depending on where we were." And, Karen (small shift) described that "the students were able to follow along with the initial activity in which they used their imagination to pretend they were an animal, and they did well in answering questions, but in the second activity there seems to have some confusion." These ideas were interesting as participants with a large shift in their DASST-C scores included more descriptions of the challenges they faced with the implementation of science lessons in the field as compared to the small shift group participants.

Experiences Within the Learning Environment. The learning environment referred to how participants designed the activities that created an atmosphere conducive for student learning. Participants from both groups (large and small shift in DASTT-C score) described their experiences within the learning environment they designed for their learner and the impact of this environment on their students' learning. Both the groups (1) experienced success with their lessons, and (2) created a hands-on student-centered learning environment for their elementary learners. For example, Sarah (large shift) described, "We wanted to create a hands-on learning experience for our students, but we also wanted to find out how much knowledge they had already acquired about the concept of camouflage. The intention was to provide an opportunity to expand their knowledge base of how animals protect themselves in the environment, as well as to modify any misconceptions they may have." However, the participants who had small shifts in their pre to post-DASTT-C scores, who had positive prior science experiences relatively, were more confident in their ability to include hands-on learning experiences. For example, Karen (small shift) described, "I allowed the students to explore the materials. This lesson was really hands-on and we made sure that each student had a turn for each trial of rolling the ball." Furthermore, the small shift group participants were more flexible to adapt their lessons according to the learning needs of their students as well as to let students test their ideas. For example, Lucy (small shift) described a situation where two of her students wanted to explore newer ways to see how the ramp height is related to how far the ball would go.

The other two boys were experimenting with the materials by lifting the ramp higher and higher to make the ball roll further. The one boy thought that if the ramp was straight up down, it would go the furthest, but when he tested it, he saw that it dropped straight down and did not roll anywhere. He learned from playing with the materials that a ramp has to have a slight tilt to allow the ball to roll. This was a great example of what students can learn if you let them explore.

On the contrary, the large shift group participants, who were designing and implementing the hands-on learning for the first time, struggled with classroom management with this new learning environment. For instance, Amanda (large shift) mentioned, "One thing that did not go well was our materials. Hands-on learning is important but attempting to control my group, hold the materials in a place where they could not get them, and facilitate the lesson was difficult." The participant struggled to keep students on the task given that the lesson involved balls, which according to her distracted one of her student from the topic. As she said, "The students kept finding a way to get a ball or a block and hiding or playing with it. The students would take the ball and rub it on their hands. It was hard not to get frustrated, and I feel as if I did a good job keeping my calm. It was frustrating because every time I had to stop to receive the material, it would take away time from the lesson."

Discussion and Implications

The study investigates preservice elementary teachers' beliefs about science learning and teaching and how a shift in these beliefs is influenced by their experiences with science learning teaching before and during a science methods course. PETs' pre and post drawings were used because they have shown to be a powerful tool to document teacher beliefs of self as science teachers, about science teaching styles, personal theories, and pedagogical attitudes regarding science teaching (Ambusaidi & Al-Balushi, 2012; Markic & Eilks, 2015; Yilmaz, Turkmen, Pederson, & Cavas, 2007). The DASTT-C tool has been utilized by prior researchers with preservice teachers at various levels of their teacher training programs to study the change in their science teaching beliefs. In this study, using DASTT-C tool allowed us to compare PETs' science teaching beliefs, however, this study also added to the literature by explaining the issue of subjective scoring and suggested a way to compare shifts in science teaching beliefs before and after a science methods course. To reveal this process of belief change this research quantified the change in PETs' science teaching beliefs by determining the amount of shift in PETs' science teaching beliefs. A large shift shows a shift from teacher-centred beliefs to student-centred beliefs, and a small shift shows a shift from less student-centered beliefs to more student-centred beliefs. This research, then investigating how PETs with a small and large shift interpret their experiences of science teaching and learning in context of a science methods course.

Past research suggests that prior K-12 science learning experiences may impact preservice teachers' beliefs at the time they enter the teacher education program (Knaggs & Sondergeld, 2015; Yoon et al., 2006). However, recent recommendations suggest a need for a rigorous investigation to develop a deeper understanding of how specific experiences (memories and episodes of science learning and teaching) impact science teachers' images (Bulder, 2017).

Regarding our findings, we observed that at the beginning of the course PETs' science teaching beliefs were more teacher-centered and authoritative in nature. More drawings showed teacher as an authority, at the center of the classroom with control over the class, materials, and students listening to them. Other studies have also found similar images held by preservice teachers at the time they enter science methods courses (Ambusaidi & Al-Balushi, 2012; Bulder, 2017; Markic & Eilks, 2015; Thomas & Pederson, 2003). Upon further investigation of PETs' science autobiographies, we found that their pre-drawings were reflections of their prior science learning experiences. For instance, reflections of how they felt as learners of science, ways they were taught by their science teachers, and the overall learning environment they were exposed to within their previous science courses. Other researchers have also claimed that these critical episodes have the power to influence PETs' existing beliefs about science teaching and learning (Goodman, 1988; Nespor, 1987; Thomas & Pederson, 2003). For those participants who had positive learning experiences (small shift) held more student-centered beliefs regarding science teaching as represented in their drawings. Conversely, participants who learned science in a traditional way (large shift) held traditional views of science teaching as depicted in their drawings. Evidently, these views as represented in their drawings were reflections of their prior experiences with science.

Changes in Beliefs Regarding Science Teaching

Previous research have noted a change in PETs' beliefs after the exposure in science methods course (Buldur, 2017; Markic & Eilks, 2015; Minogue, 2010). In this study, we further investigated the change in terms of small and large shifts in context of the science methods course. Evidently, learning reform-based pedagogies as well as planning and implementing the science lesson using those pedagogies proved crucial towards causing such a change. Interestingly, the participants (large shift) who held negative beliefs about science teaching, owing to their prior experiences, experienced a positive shift in their science teaching beliefs because of the successful teaching experiences in the field. This tendency was found in the reflections on their science teaching where participants found appreciation and value in science teaching using student-centered styles of teaching. Other factors that may have impacted participants' positive beliefs about science teaching (as depicted through their drawings) include understanding the context that includes what to expect when teaching science with younger students, more familiarity with the classroom environment, the improved vision of how pedagogical strategies impact student learning.

Regardless of the nature of their prior experiences, PETs (both small shift and large shift) in this study had greater success in engaging their learners and were able to witness that the student-centered environment could help students learn, as evident from the qualitative analysis of participants' reflection papers. These episodes of success solidified their confidence in themselves as science teachers. More drawings showed the teacher acting as a *guide* and as a *facilitator* as opposed to the head of the class. Also, the drawings depicted students taking active roles in hands-on scientific investigations and figuring things out on their own. Interestingly, many drawings showed science learning in informal learning environments such as students outside the classroom with hand lenses or observing trees in the garden. These findings are in accord with other studies which had found a shift in PETs' beliefs from traditional to more student-centered instruction after their participation in the science methods coursework (Buldur, 2017; Minogue, 2010; Thomas & Pederson, 2003). Our study adds to the literature by providing evidence on how teachers' beliefs are linked to personal histories and critical incidents regarding their prior science experiences. Based on our results, we conclude that successful teaching experiences have a potential to influence PETs' self-images as science teachers.

Implications for Practice and Future Research

There are important implications for PET education given the results showing positive shifts in PETs' beliefs owing to personal success with science teaching. Often times, students confront student-centered learning approaches and reform-based pedagogies during science methods course that they may not have experienced as science learners. Science teacher educators must provide continuous support and mentoring to PETs as they confront and revisit their beliefs regarding science teaching. It is well known that new and positive experiences gained during science methods courses help support self-efficacy beliefs and positive science teacher self-image (Menon, 2018) thus, more opportunities are needed for PETs to plan, design, practice, and implement science lessons with new pedagogies they learn in methods courses. We may hope that successful personal experiences in the field may create new images that PETs may rely on for their science instruction. Given this conjecture, more longitudinal studies are needed to explore how and whether images formed during the teacher training program inform future practices.

In this study, we found that PETs' personal experiences as science teachers, their engagement with learners, and the learning environments impacted their science teaching beliefs. What added value to their student-centered beliefs is reflecting on their own practices as they were able to analyze elements of effective science teaching. Written science autobiographies also helped participants to recollect their memories from prior science experiences and challenge their beliefs about science teaching as they experience new strategies for teaching science. Therefore, opportunities for reflective practice are required for PETs in science methods courses. Additionally, a closer look at how views and perceptions are emerging with each additional teaching practice must be explored longitudinally. Studies should continue to explore elements of science methods courses and field-experiences that impact teachers' science teaching beliefs in the long-term. Such exploration must consider including multiple data sources to provide rich descriptions of changes in PETs' beliefs regarding science teaching.

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Appendix A

Draw & Explain Yourself as a Science Teacher

1. **What is the teacher doing? What are the students doing?** ______________________________
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____

2. **Where are they? What is happening?** ____
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Appendix B

DASTT-C Scoring Scheme (Thomas, Pedersen, & Finson, 2001)

	Category	Sub-Category	Description	Present/Absent 1/0
I	Teacher	**Activity**	Demonstrating Experiment/Activity	
			Lecturing/Giving direction (Teacher talking)	
			Using visual aids (chalkboard, overhead, and charts)	
		Position	Centrally located (head of class)	
			Erect posture (Not sitting or bending down)	
II	Students	**Activity**	Watching and listening (or so suggested by teacher behavior)	
			Responding to teacher/text/questions	
		Position	Seated (or so suggested by classroom furniture)	
III	Environment	**Inside**	Desks are arranged in rows (more than one row)	
			Teacher desk/table is located at the front of the room	
			Laboratory organization (equipment on teacher desk or table)	
			Symbols of teaching (ABC's, chalkboard, bulletin boards, etc.)	
			Symbols of science knowledge (science equipment, lab instruments, wall charts, etc.)	
			Total Score	**___ /13**

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Exploring Latinx Parent Involvement in Informal Science Activities

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ABSTRACT

Diversity has been shown to improve the ability of groups to problem solve and make predictions, as well as guarding against groupthink and overconfidence. Marginalized groups within the Science, Technology, Engineering, and Mathematics (STEM) fields are still largely underrepresented despite various efforts to increase diversity in STEM. This study focused on the gap in representation of Hispanics/Latinxs in the STEM fields. While most science programs focus on directly encouraging students to pursue STEM careers as a way to increase Latinx representation, our study focused on Latinx parents. This study explored the types of informal science activities Latinx parents engage in with their children. In order to connect with Latinx parents, we organized 15 family science night events in a small city in central Texas that has a large Hispanic population. At the events, parents completed a parental involvement survey to find out what types of informal science activities they are involved in with their children. We utilized common household items or materials that were inexpensive in designing the activities for the family science events to ensure they were accessible to all families. Eighteen Latinx parents participated in the study. On the parental involvement survey, Latinx parents identified 27 science activities that they have performed with their children, with 63% of those being structured and indoor activities and 59% being free activities. In terms of parent participation, the majority of Latinx parents (73%) preferred free activities. This study outlines the design of family science events and can help inform school districts, principals, teachers, and informal science education organizations on strategies for increasing Latinx parents' involvement in their childrens' science education.

Keywords: family science, Latinx, parents, parental involvement, STEM

Introduction

In order for the United States to remain competitive economically with other countries, science, technology, engineering, and mathematics (STEM) careers are necessary (Christensen, Knezek, & Tyler-Wood, 2015). A better economy, better jobs, and new industries were seen as the number of graduates with STEM degrees increased after World War II (Holdren & Lander, 2012). A major factor for the U.S. having one of the best economies globally can be attributed to those working in the STEM fields (Christensen, Knezek, & Tyler-Wood, 2014; 2015). These STEM professionals have created important and useful products that have become increasingly intertwined in the lives of U.S. citizens (Holdren & Lander, 2012). Today, there are increasing career opportunities being created that need to be filled as the United States continues to push the boundaries of science.

College Graduates with STEM Degrees

Between 2008 and 2018, STEM jobs were projected to grow by 17% according to the Center on Education and the Workforce at Georgetown University (Carnavale, Smith, & Melton, 2011). Furthermore, it has been estimated that the amount of STEM jobs requiring at least some college is 91% (Carnevale, Smith, & Melton, 2011). Currently, the number of students graduating with a STEM degree is not keeping pace with the increasing numbers of STEM jobs (Chen & Simpson, 2015; Christensen, Knezek, & Tyler-Wood, 2014; Knezek, Christensen, Tyler-Wood, & Periathiruvadi, 2013). In addition, those who entered college planning to major in STEM and then graduating with a STEM degree is less than 40% (Holdren & Lander, 2012). The percent of those STEM graduates is even less for those that are historically underrepresented in STEM which include Hispanic/Latinx, Black/African-American, and Native-American/ Native Alaskan. Also, only about 18.7% of STEM working professionals are of an underepresented population (National Center for Science and Engineering Statistics (NCSES), 2019), which is disproportionate compared to their representation of 33.2% in the U.S. population (United Stated Census Bureau, 2019). This disparity illustrates the need for the United States to better utilize a large group of its population for our country to reach its full potential in the STEM fields.

Workplace Diversity

Innovation stemming from diversity within teams has been acknowledged by various companies and organizations (Tachibana, 2012). Google has acknowledged their lack of diversity and addressed it by expanding access to careers in technology, strengthening their community outreach, broadening their supplier network, and creating inclusive products ("Diversity | Google," 2018). Universities are also making efforts to increase diversity within their institutions, including Texas State University. One of the five goals for Texas State University is to enrich their learning and working environment by attracting and supporting a more diverse faculty, staff, and student body ("Diversity Plan," 2012).

Groupthink and overconfidence are characteristics found in less diverse groups, which can be guarded against through diversity within groups (Brodock & Massam, 2016). When deciding where to apply and when accepting employment, Glassdoor found the majority (67%) of job seekers consider a company's diversity ("What job seekers really think of your diversity stats," 2014). Furthermore, diversity within groups improves the ability to make predictions (Page, 2007) and to solve problems (Tachibana, 2012). Studies have reported increased net profit margins (Tachibana, 2012), increased employee ratings, and decreased project costs (Brodock & Massam, 2016) as benefits of gender diversity.

Diversity within STEM Fields

In 2008, there was a large effort to increase diversity within the STEM fields throughout the Obama presidency (Handelsman & Smith, 2016). Handelsman and Smith (2016) reported these efforts included billions of dollars worth of investments towards 14 federal agencies dedicated to STEM education in 2016, as well as the *Educate to Innovate* campaign, and goals to prepare 100,000 math and science teachers by 2021. To show its priority to STEM education, the Department of Education during Obama's presidency hosted the *White House Science Fair*, along with its support of the *Race to the Top* competition, and encouraged post-secondary education leaders to provide historically underrepresented students with pathways to attain STEM degrees. To further prioritize STEM education, Obama's 2017 budget provided millions of dollars towards Next-Generation High Schools, Student Support and Academic Enrichment grants, Teacher and Principal Pathway programs, expansion of computer science programs, and increasing diversity in STEM (Handelsman & Smith, 2016).

Latinx Representation in STEM Fields

There has not been much change in the representation of Latinxs in STEM fields, despite efforts to increase diversity within STEM fields. Over the years, the Latinx population in the U.S. has steadily grown, while the White population has decreased in percentage (Table 1) (USCB, 2010; 2015; 2019). Within the STEM field, Latinx representation has grown, but not by much. The Latinx population remains underrepresented in the STEM fields compared to Whites in STEM (Table 2) (NCSES, 2013; 2019, USCB, 2015). See Table 1 and Table 2 for data comparisons. This illustrates that despite growing in number in the overall population, Latinxs are still underrepresented in the STEM fields. In addition, Latinxs face many challenges on their path to becoming STEM professionals, despite the many efforts to increase diversity with the STEM fields.

Table 1
Latinx and White in U.S. Population

Year	Latinx (%)	White (%)
2010	16.4	63.6
2015	17.6	61.45
2018	18.3	60.4

Note. Data from 2010 taken from USCB (2010)
Note. Data from 2015 taken from USCB (2015)
Note. Data from 2019 taken from USCB (2019)

Table 2
Latinx and White Representation in STEM

Year	Latinx (%)	White (%)
2013	6	51
2015	6.6	70.75
2017	8.6	67.8

Note. Data from 2013 taken from NCSES (2013)
Note. Data from 2015 taken from USCB (2015)
Note. Data from 2017 taken from NCSES (2019)

STEM Education for Latinxs

In pursuing a career in the STEM field, Latinxs face numerous obstacles in their education. Flores (2011) listed the various obstacles Latinxs face: not being exposed to culturally relevant science curriculum, not being prepared for college course work, not being encouraged to pursue STEM careers, and not being exposed to Latinx mentors in STEM. In addition to these obstacles, families of Latinx students may not have the knowledge to assist their children in pursuing STEM careers and may not even be aware of career opportunities within STEM (Flores, 2011). Hernandez, Rana, Alemdar, Rao, and Usselman (2016), reported that Latinx parents recognize their lack of knowledge of STEM careers and STEM opportunities for college students, but are aware of the many challenges faced by their children. Out of school or informal science programs has been shown to influence youth to choose science as a career, increase achievement in science, and provide conversations with family members about science topics (Bruyere & Salazar, 2010). Bruyere and Salazar (2010) reported that Latinxs are highly interested in informal science education and prefer programs that involve the entire family. The purpose of this study is to examine what types of informal science activities that Latinx parents prefer to engage in with their children.

Conceptual Framework

To form our conceptual framework that Latinx student interest in science is influenced by Latinx parents, we focused on three studies that concerned Latinx student interest in science and the connection to Latinx families. As described earlier, Flores (2011) discussed the various obstacles Latinx school children face in their science education and that many Latinx parents lack knowledge in science making it difficult to assist their children in science. (Flores, 2011). Authors Hernandez, Rana, Alemdar, Rao, and Usselman (2016), stated that Latinx parents understand they lack knowledge in STEM careers and STEM opportunities for college students. However, they are very aware of the many challenges faced by their children. Authors Bruyere and Salazar (2010) highlighted the importance of informal science programs for Latinx families as a means of encouraging Latinx youth to explore science as a career.

Theoretical Framework

The theoretical framework we propose to support our conceptual framework is that families that learn together, that is emphasized in our family science nights, promotes both student and parental interest in science. Latinx families, in particular, have a strong sense of "familismo" or sense of loyalty toward the family" (Hernandez et al. 2016 p. 357). This means that conversations about educational topics, including science, tend to include <u>all</u> members of the family. Araque et al. (2017) noted that, "Given Latino culture's emphasis on collectivism and family bonds, it follows that most Latinx parents report providing informal educational support for their children at home ...providing emotional support" (p.233). Hernandez et al. (2016) also described the parental motivation of Latinx children as, "Latino parents ...encourage and motivate their children by providing verbal and emotional support." Family science events provide an opportunity for parents to provide that support and thereby motivate children to develop an interest in STEM. Hernandez et al. (2016) described, in their GoSTEM programs, how a mother motivated her daughters at home. "One mother wrote, [I learned] how to do the experiments at home as this will be very fun for my daughters. I wish there were more workshops in the summer to motivate children" (Hernandez et al. p.360).

Programs that are similar to building interest in science through Latinx family activities are those that build interest in literacy or reading through family activities. A Latinx child's interest in reading appears to increase as the parental interest in reading increases (Larrotta & Ramirez, 2009). It is important that parents develop a skill for literacy just as we see in science skills such as in observation. Development of skills in parents whether in literacy or in science helps them to be better *motivators* for their children's interests in reading or in science concepts. As Larrotta & Ramirez, (2009) noted, "If we want to become more efficient literacy instructors, it is important that we understand that in order for the parents to help in the development of their children's literacy skills, the parents themselves must first develop their own (p.629).

The family science nights that we designed through the use of science journals were for students <u>and</u> parents to be actively involved *together* and to develop skills together. We encouraged the collaboration between parents and their children rather than collaboration with a "teacher". Correct answers were not the objectives of our family science night activities. Instead, we were interested in whether students and their parents became more motivated to learn science by working together in the family science program and at home. By using a collaborative approach in the activities where student/parent teams are engaged first followed by exploration, the students and their parents had a "greater feeling of autonomy". Autonomy was emphasized by Ryan and Deci (2000) as being important in the development of motivation to learn content. Thus, our theoretical framework to promote interest in science is based upon families that learn science together through simply being together, skill building and feelings of autonomy.

Literature Review

George (2000) found that children's attitudes towards science become less positive during their middle and high school years. Furthermore, children are more likely to pursue science in college if they develop an interest in science before they reach middle school (George, 2000). When Latinx children receive only minimal support in their school studies at home, their achievement in education decreases (Rochin & Mello, 2007). Culturally, Latinx parents believe that education is the responsibility of the school and the child's well-being is the responsibility of the parents (Ramirez, McCollough, & Diaz, 2016). Castaneda (2006) found that Latinx parents are highly concerned about their children's education but lack the knowledge to support their children. And, when Latinx parents are given the opportunity to participate in family science activities, they are interested in bringing these activities back to their home (Hernandez, Rana, Alemdar, Rao, & Usselman, 2016).

Family Science Nights

Family Science Nights have reported benefits for students and parents, and are becoming more popular in K-12 educational settings. These student benefits include, increased confidence and increased interest in science when their parents are involved in their learning (Kaya & Lundeen, 2010), and greater academic success (Lozar, 2012; Ramirez, McCollough, & Diaz, 2016). Although, long-term parental involvement is difficult to maintain once a program is over, research has shown that parents become more supportive of their children's science learning when hands-on activities are provided (Kaya & Lundeen, 2010; Perera, 2014).

Family Night programs can be found back to the 1980s (McDonald, 1997) and have been organized for students throughout the United States in elementary schools (Grote, 2000; Kaya & Lundeen, 2010), middle schools (Mitchell, Drobnes, Colin-Trujillo, & Noel-Storr, 2008; Yanowitz & Hahs-Vaughn, 2016), and high schools (Hansen-Thomas & Alderman, 2016). Mostly, Family Science Night programs focus on student involvement instead of parent involvment. Although parental involvement increases in science because of the event, it is difficult to maintain this involvement long-term. Typically, Family Night programs are one-night events with a large time interval between the next Family Night. Most of these programs are not monitoring parental involvement once the event is over. These Family Science Night programs have evolved to include pre-service teachers (Bottoms, Ciechanowski, Jones, de la Hoz, & Fonseca, 2017; Valadez & Moineau, 2010) and English language learners (Hansen-Thomas & Alderman, 2016). The purpose of Family Night programs is to engage parents in their children's learning, and overall, these studies indicate family involvement is beneficial for students (Grote, 2000; Hansen-Thomas & Alderman, 2016; Kaya & Lundeen, 2010; McDonald, 1997; Mitchell, Drobnes, Colin-Trujillo, & Noel-Starr, 2008; Yanowitz & Hahs-Vaughn, 2016). There is a need to find out what types of informal science activities parents are taking part in with their children. This information can be used to explore how Family Science Nights can be used to better serve parents in becoming more involved in their children's science learning.

Research Question

What types of informal science activities do Latinx parents engage in with their children?

Pilot Study

In June and July of 2017, we organized three family science nights at the local library in a small city in central Texas. This was part of a pilot study to determine whether our family science events were organized appropriately to address our research question. Prior to the pilot study, we were granted IRB Exemption 2017763 by the Institutional Review Board. At the public library, we organized family science events on Wednesdays from 6pm-8pm, on June 28, July 5, and July 12. Data from these three family science events were not used in the analysis of this study because changes were made to the following 15 family science events that we used for this study. These changes will be explained further, but they include changes to the family science event format and structure, and data collection.

Parent/Guardian Continued Participation and Mail-In Involvement Questionnaire.

At the beginning of each Family Science Night, during the pilot study, we provided parental consent forms that were filled out before any data collection was taken in accordance with the university Institutional Review Board (IRB) guidelines (Appendix C). Also, the parents were given the parent/guardian involvement questionnaire as a take-home questionnaire along with a pre-addressed and stamped envelope (Appendix D). We received only a few questionnaires back in the mail from parents/guardians using this strategy. Thus, the strategy was a data collection barrier for determining parental involvement in their children's informal science education. We changed our strategy by collecting all data at the family science events. We also chose to survey parents before the event with an involvement survey. By changing our strategy, we received more data concerning informal science activities conducted with their children and their comfort level with science and family science events.

Methods

Study Sites – Research Study

Over the course of two years, we organized 15 family science events throughout a small city in central Texas. This city is about 41% Hispanic/Latinx and 49% White, 34% have a bachelor's degree or higher, and the median household income is $37,593 (USCB, 2020). These events were conducted at the local public library, a government assistance section 8 housing complex, and the Hispanic cultural center. We chose these locations because we wanted sites that Latinx families would visit. Also, all of the locations chosen already had programed family oriented events. At the public library, the family science events were scheduled from 6pm-8pm on Wednesday, July 26, August 2, and August 9 of 2017. The following year in 2018, we organized six additional events from 6pm-8pm on Thursday, August 2, 9, and 16, and from 10:30am-12:30pm on Saturday, August 4, 11, 18. At the government assistance section 8 housing complex, the family science events were scheduled from 6pm-8pm on Monday, October 9, 16, and 23 of 2017. At the Hispanic cultural center, the family science events were scheduled from 10am-12pm on Saturday, September 16, October 21, and November 18 (See Table 3 for number of attendees at each study site).

Table 3

Number of Participants at Each Study Site

Study Site	#
Public Library	22*
Section 8 Housing Complex	8**
Hispanic Cultural Center	5**

Note. We had a total of n=31 participants with one participant attending four events and another participant attending two events.

Note. Values with '*' include participants who attended an event at another study site

Note. Values with '**' include participants who attended more than one event at that study site.

Study Setting

The space at the public library was about the size of a large classroom, the Hispanic Cultural Center was about the size of a medium classroom, and the space at the section 8 housing community was about the size of a small conference room. All of the study sites had movable tables and chairs, as well as easy access to the outside for certain activities. They all had running water, electricity, electrical outlets, access to internet/wifi, computers, as well as a projector for us to use. In addition, the study sites provided various supplies such as, pens, pencils, markers, rubber bands etc., and disposable materials like paper plates, cups, and napkins.

Participants

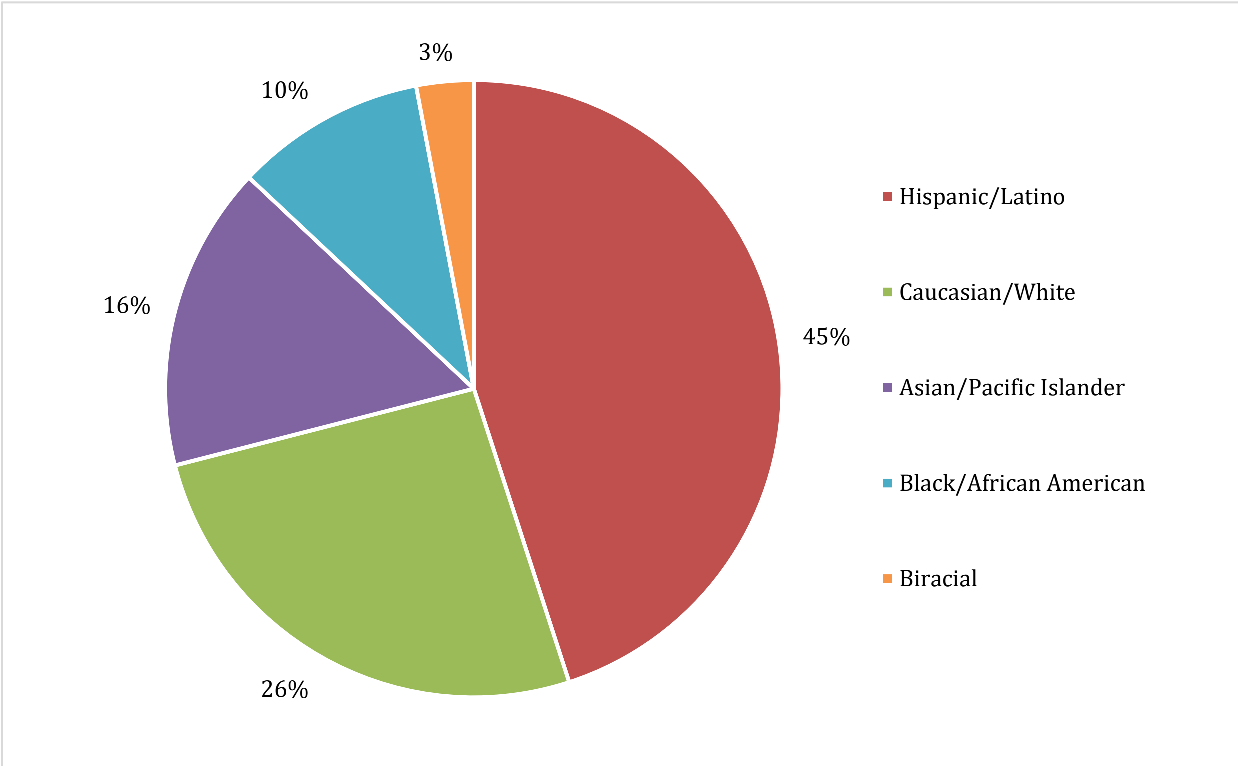
For our study, we focused on parents or guardians with children that were 9-12 years old, because this is the time period that most children begin to lose an interest in science (George, 2000). Parents and guardians with children outside of this age range were still allowed to participate. We required all children participating in the family science event to be accompanied by a parent or guardian. The parents/guardians were our research participants for this study, while their children were just event attendees who participated in the program activities. Out of the 31 parents/guardians that participated in the study, 45% identified themselves as Hispanic/Latinx (Fig. 1; Table 4). Of the Latinx participants, 71% were mothers (Fig. 2), 43% had completed graduate/professional degrees (Fig. 3), and 86% had their children in public school (Fig. 4).

Table 4

Family Science Participants by Ethnicity (n=31)

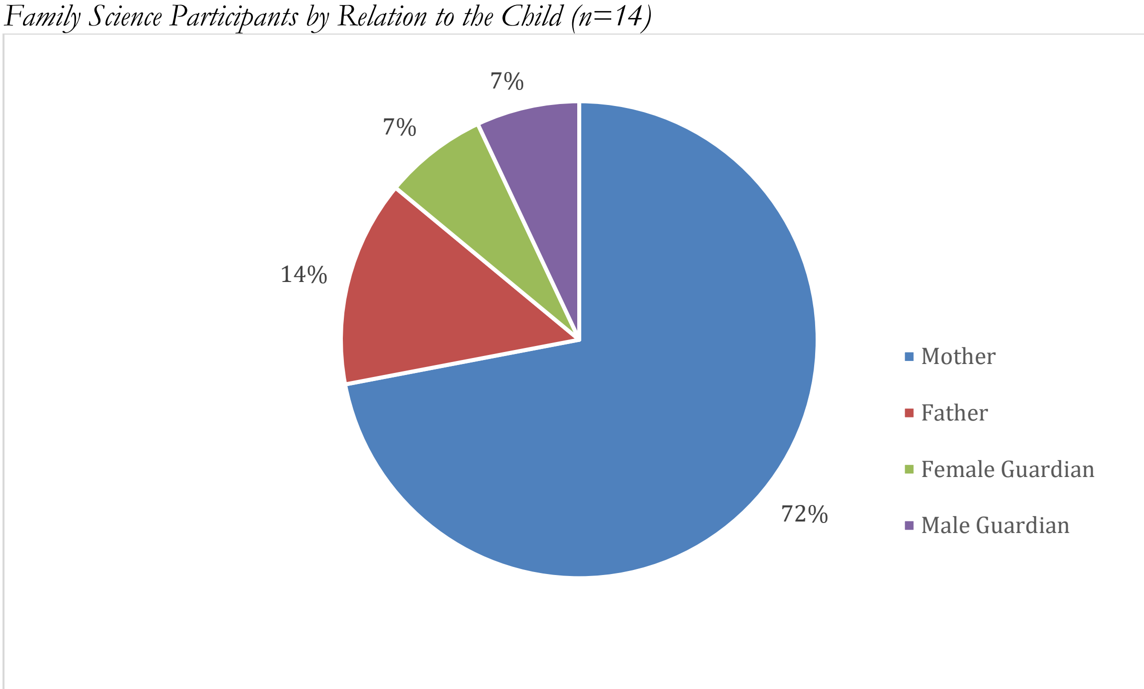
Ethnicity	n	%
Hispanic/Latinx	14	45%
Caucasian/White	8	26%
Asian/Pacific Islander	5	16%
Black/African American	3	10%
Biracial	1	3%

Figure 1
Family Science Participants by Ethnicity (n=31)



Note. Of the parents that participated in the study, 45% were Hispanic/Latinx.

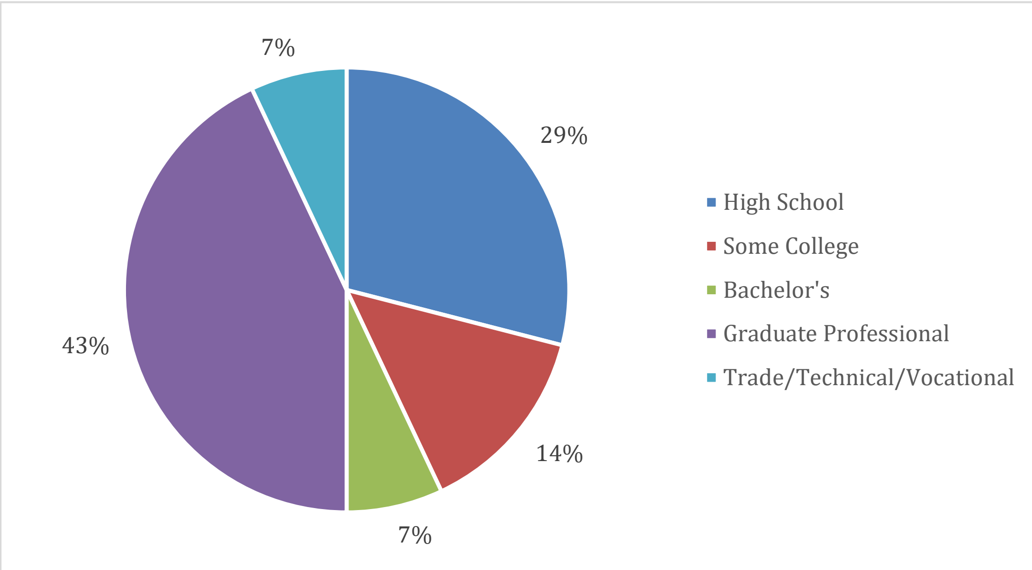
Figure 2
Family Science Participants by Relation to the Child (n=14)



Note. The majority (72%) of the 14 Latinx parents that participated in the study were mothers of the children that were brought to the family science events.

Figure 3

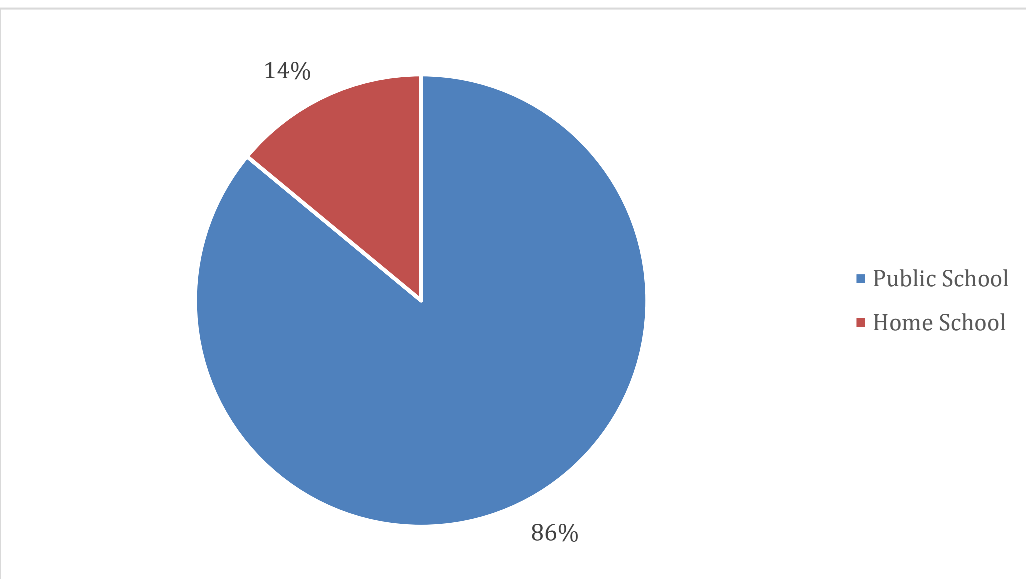
Family Science Participants by Education (n=14)



Note. A large portion (43%) of the 14 Latinx parents that participated in the study had a graduate/professional degree.

Figure 4

Family Science Participants by Type of School (n=14)



Note. The majority (86%) of the 14 Latinx parents that participated in the study had children in public school.

Recruitment of Participants

Participants were recruited primarily by each of the study site directors. Although I did design a flyer for our science events, in both English and Spanish, each study site marketed our science events in their own way. They all placed fliers around their establishment, on marquees and digital screens, as well as sending word out through their own email lists. The parents that decided to participate in this study self-selected to participate and were not compensated monetarily.

Family Science Event Structure

During the pilot study, we observed that the parents/guardians were not engaging with their children on the science activities. Types of disengaged behavior that we observed were parents/guardians watching their children work on the science activity, leaving their children alone during an activity and either sitting off to the side or doing something else other than assisting their child with the science activity. To promote more parental engagement with their children, we adjusted the set-up of my events. Initially, we set-up my family science events to resemble a *gallery walk* (Appendix A). In this set-up, there were six stations with a different science activity that participants could perform in any order. Participants were not required to complete all six activities. A volunteer was placed at each station to facilitate that activity and to answer any questions. After the pilot study, we adjusted my event set-up to resemble a *workshop*. In this set-up, we placed tables in rows and only one volunteer led the facilitation of the science activities to all of the participants at the same time. To promote more engagement among the parents/guardians, we created science journals for each event with instructions for the activities in the science journals (Appendix B). We also indicated duties that the parent would perform and duties that the child would perform. After making these adjustments, we observed more engaged behavior from the parents/guardians, as well as a decrease in the amount of volunteers and the cost for each event.

Family Science Event Activities and Materials

It was our goal for the activities performed at the family science events to be accessible to all families. We wanted the activities to be fun and engaging for both the parent and child, as well as relevant to the timeframe the events took place. For example, we built eclipse viewers before the 2017 eclipse. In addition, we chose activities that made use of materials many families would already have in their homes or could be cheaply purchased at the store. To give an example, to prepare for the solar eclipse on August 21, 2017, we had participants build eclipse viewers with their children. This activity only required a cardboard box, aluminum foil, white printer paper, tape, scissors, and a pin. In another activity, where participants made balloon rockets, it simply required a balloon, a straw, string, tape, and scissors (See Table 5 for descriptions of activities).

Data Collection

At the start of the family science event, parents signed parental consent forms, as they did in the pilot study, and initialed questionnaires so that it could be determined whether they participated in more than one family science event. We collected data from a pre-event parent/guardian involvement questionnaire that was modified in 2018 (Appendix D in 2017 & Appendix E in 2018). The modified pre-event parent/guardian involvement questionnaire made the instrument easier for the parents/guardians to complete and increased the quality of the data collected.

Table 5
Descriptions of a Sampling of Activities Used in the Family Science Events

Measuring Shadows	The purpose of this activity was to explore the relationship between the size and position of shadows and the position of the sun. The parent and child would go outside at various times of the day and the parent would measure their childs' shadow at each of these times. Then the parent and child would take a look at the measurments to see how the measurments changed throughout the day.
Magic Tape	The purpose of this activity was to explore static electricity. Placing two strips of tape down on a table and ripping them off will demonstrate a pushing effect of the pieces away from each other. Placing one strip of tape on a table and then placing another strip directly on top of the first strip will demonstrate a pulling effect of the pieces towards each other.
Microscope Fun	The purpose of this activity was to learn how to use a microscope and preparing dry mount slides. The parent would help the child cut out different pieces of newspaper and magazines to look at under a microscope.
Microscopes and Microorganisms	The purpose of this activity was to learn how to make a wet mount slide and explore microorganisms in pond water. After looking at a drop of pond water, the child is instructed to pick something they see in their microscope and draw it.
Mutations in Fruit Flies	The purpose of this activity was to explore mutations in fruit flies. The parent would help their children look at samples of fruit flies with hand lenses and microscopes to determine which mutation each sample had.
Frankenstein's Hand	The purpose of this activity was to explore the chemical reaction that occurs between baking soda and vinegar. The role of the parent is to help their child add some vinegar to a cup and then add some baking soda into a disposable glove. Then the parent helped the child place the glove around the rim of the cup without spilling baking soda into the cup. Once the glove is firmly around the cup, the child is assisted to lift the glove to empty the baking soda into the cup. The reaction will produce a gas which will then fill up the glove giving off the impression that it is alive.
Cloud Spotting	The purpose of this activity was to explore the different types of clouds. The role of the parent was to take their child outside and take a look at the sky. With the help of a cloud identification chart, the parent helped their child identify the types of clouds in the sky.
I, Robot	The purpose of this activity was to build a model of the ISS End Effector arm and explore robots and how they are used in space. The role of the parent is to help their child build this model using common household materials. Then test their model robot to see what sorts of things it could pick up and move.
Balloon Rockets	The purpose of this activity was to observe Newton's Third Law of Motion. The role of the parent is to help their child cut a length of string and run it through a straw. Then attach the string between two sturdy objects. Next the parent would help their child blow up a ballon and pinch it shut while taping it to the straw on the string. Then let the balloon go and see what happens.
Eclipse Viewers	The purpose of this activity was to build an eclipse viewer to view the 2017 eclipse safely. The role of the parent is to help their child construct an eclipse viewer out of common household products.

Instruments

We used the pre-event parent/guardian involvement questionnaire to find out what types of informal science activities parents engage in with their children. The questionnaire included a list of various activities that parents were asked to provide a number of how often they participated in that activity with their child/children. The questionnaire also included two additional open-ended free response questions. Demographics collected on the involvement questionnaire were the parent participant's self-identified ethnicity, relationship to the child, and highest level of education. The parent/guardian involvement questionnaire was based upon the parent involvement survey developed by Dr. Hunter Gehlbach and his research team of Dr. Karen Mapp and Dr. Richard Weissbourd at the Harvard Graduate School of Education. Dr. Gehlbach and his research team made use of a multi-step process in developing surveys to ensure high validity and reliability. This multi-step process included an extensive review of the literature, interviews and focus groups, development of items, validation by experts, cognitive pretesting, and then piloting the surveys (Bahena, Schueler, McIntyre, and Gehlbach, 2016; Artino, La Rochelle, Dezee, and Gehlbach, 2014; Schueler, Capotosto, Bahena, McIntyre, and Gehlbach, 2014; Gehlbach and Brinkworth, 2011).

Translation of Materials

We provided Spanish translations of all family science events materials, including the science journals with the activities, consent form, and surveys. However, none of the materials translated in Spanish were ever requested. The Latinx parents that participated in the study preferred the English materials.

Data Analysis

We used an independent inductive approach to analyze the parent/guardian involvement questionnaires and apply descriptive codes to the data. After our initial descriptive codes were created independently, we met and discussed similarities in our codes (Patton, 1990). After the final selection of codes, we then identified patterns of Latinx parental involvement in informal science activities (Saldaña, 2016).

Results

Parental Involvement

Our research question focused on the types of informal science activities that Latinx parents engaged in with their children. Parent/guardian participants completed the parent/guardian involvement questionnaire <u>before</u> our family science events (Appendix E; Appendix F).

Family Science Event Participation

There were 15 family science events. Of the Hispanic/Latinx participants surveyed (n=14), only two participated in more than one family science event. One of these parents attended four events and the other attended two events.

Parent Participation in Activities

The top two of the 27 coded listed activities that parents participated in with their children at home were talking about science (14%) and visiting the library (13%) (Table 6). To understand the nature of the science activities, the activities were clustered into *Inside/Structured*,and *Outside/Discovery*, in Table 7. *Free* and *Paid* activities were clustered separately in Table 8. *Inside/Structured* activities are activities that are typically done inside and have some sort of structure or organization by way of a guide or the infrastructure of the location. *Outside/Discovery* activities are activities that are typically done outside and have no direction with regard to content. *Free* activities are activities that do not require a fee to participate in and *Paid* activities are activities that require a fee to participate in. Talking about science was not included in these calculations because I decided that this activity could be done inside or outside and could be a structured or discovery activity. As a result, the percentages do not add up to 100% for all types of activities. Note in Table 7, there were more *Indoor/Structured* activities that parents listed than *Outside/Discovery*. *Indoor/Structured* activites were varied from visiting an aquarium to watching science Youtube clips. *Outdoor/Discovery* activities were also varied from collecting rocks to observing the night sky. It is interesting to note that parents did not describe any activities that were discovery oriented and inside. There were also more free activities than paid activities described by the parents. An example of a free activity is attending a science fair. An example of a paid activity is visiting a zoo. Table 9 displays how often parents participated in *Inside/Structured*, *Outside/Discovery*, *Free*, and *Paid* activities. There was 55% parent participation for activities that were *Inside/Structured* activities, whereas 32% were *Outside/Discovery*-oriented activities (Table 9). Lastly, there was 73% parent participation for *Free* activities and 27% for *Paid* activities (Table 9). Overall, Latinx parents listed participating in *Indoor/Structured*, and *Free* activities more than *Outdoor/Discovery*, and *Paid* activities.

Types of Activities

Parent participants identified 27 separate science activities (Table 6) they performed with their children outside of our family science events on the Parent/Guardian questionnaire (Appendix E). Of the 27 activities mentioned by the parents, 63% of activities were structured and could be done inside the home and 33% were discovery-oriented and could be done outside (Table 7). And, 59% of activities were free activities whereas 41% of activities required a fee (Table 8).

Table 6

Activities Performed by Hispanic/Latinx Parents/Guardians with their Children (n=18)

Activity	% Participation in Activity	Activity	% Participation in Activity
Talked About Science	14% (16)	Watched Science TV Show	2.6% (3)
Visited Library	13% (15)	Attended Science Event	2.6% (3)
Worked on Home Science Projects	7% (8)	Birdwatched	2.6% (3)
Collected Rocks	5% (6)	Observed Weather	2.6% (3)
Went on A Nature Walk	5% (6)	Visited Aquarium	1.8% (2)
Watched Science Documentary	5% (6)	Worked on Science Activity Kit	1.8% (2)
Read Book on Science	4% (5)	Taught Science in Homeschool	0.9% (1)
Visited Museum	4% (5)	Watched Science Clips on YouTube	0.9% (1)
Explored River	4% (5)	Attended Science Fair	0.9% (1)
Observed Night Sky	3.5% (4)	Observed Nature	0.9% (1)
Went for a Hike	3.5% (4)	School Fieldtrips	0.9% (1)
Gardened	3.5% (4)	Visited Zoo	0.9% (1)
Researched Science Online	3.5% (4)	Worked on Science Activities Online	0.9% (1)
Helped with School Work	2.6% (3)	Total	114

Note. Values in parenthesis represent raw numbers of parental responses.

Table 7
Activities Clustered by Inside, Outside, Structured, and Discovery

Inside/Structured Activities	Outside/Discovery Activities
Visited Library	Collected Rocks
Worked on Home Science Projects	Went on a Nature Walk
Watched Science Documentary	Explored River
Read Book on Science	Observed Night Sky
Visited Museum	Went for a Hike
Researched Science Online	Gardened
Helped with School Work	Birdwatched
Watched Science TV Show	Observed Weather
Attended Science Event	Observed Nature
Visited Aquarium	
Worked on Science Activity Kit	
Taught Science in Homeschool	
Watched Science Clips on YouTube	
Attended Science Fair	
School Fieldtrips	
Visited Zoo	
Worked on Science Activities Online	

Table 8
Activities Clustered by Free and Paid

Free Activities	Paid Activities
Talked About Science	Watched Science Documentary
Visited Library	Read book on science
Worked on Home Science Projects	Visited museum
Helped with School Work	Research science online
Attended Science Event	Watched science tv show
Taught Science in Homeschool	Visited aquarium
Attended Science Fair	Worked on science activity kit
Collected Rocks	Watched science clips on youtube
Went on a Nature Walk	School field trips
Explored River	Visited zoo
Observed Night Sky	Worked on science activities online
Went for a Hike	
Gardened	
Birdwatched	
Observed Weather	

Table 9

Types of Activities Performed by Hispanic/Latinx Parents with their Children (n=18)

	% Types of Activities	% Parent Participation in Activity
Inside/Structured*	63% (17)	55% (63)
Outside/Discovery*	33% (9)	32% (35)
Total	(27)	(114)
Free	59% (16)	73% (83)
Paid	41% (11)	27% (31)
Total	(27)	(114)

Note. Items with an asterisk do not include the activity talking about science.
Note. Values in parentheses represent raw numbers of responses.

Discussion

Latinx Parent Involvement

For our research question, we wanted to know what types of informal science activities Latinx parents are engaging in with their children. Fifty-five percent of Latinx parents mentioned participating in structured activities that could be done inside, and 73% of Latinx parents' mentioned free activities. The data indicate that Latinx parents in our study seem to be more engaged with their children in free and structured activities that can be done inside. Since most Latinx families have low socioeconomic status (SES), free activities would be highly appealing (USCB 2017a). The American Psychology Association (2018) defines socioeconomic status (SES) as quality of life attributes as well as the opportunities and privileges afforded to people within society, which include income, education, and social status. According to the United States Census Bureau (2017a), 25% of all Hispanic families make less than $30,000 whereas 12% of white families make less than $30,000. Also, on average, Hispanic families make $37,000 less than White families. In addition, the median household income for the city our study was completed in is $37,593 (USCB, 2020). Free science activities may be all that Hispanic families can afford for science education enrichment.

The preference of Latinx parents for *structured* activities that can be done inside may be connected to their level of education. Castaneda (2006) and Kaya and Lundeen (2010) found that Latinx parents do not have the necessary knowledge and skills to assist their children with science activities. According to the United States Census Bureau (2017b), 28% of Hispanics have less than a high school diploma and 18% have a bachelor's degree or more. Whereas, 6% of Whites have less than a high school diploma and 39% have a bachelor's degree or more. This may explain why 55% of the Latinx parents that participated in our study preferred structured activities that included a guided component over discovery-based activities. Examples of structured types of activities include family science events at local public establishments, watching science documentaries or YouTube videos, or reading books on science. Doing more structured and guided science activities with their children may be their solution for their lack of knowledge in science. Interestingly, a large percentage, 44%, of Latinx parents that participated in our study had a bachelor's degree or higher, which is more than double the national value. This is also higher than the education level of the city our study took place in which contains 34% with a bachelor's degree or higher (USCB, 2020). If it can be assumed that Latinx parents in my study know more about science due to their high education levels, then one would have expected they could assist their children in both structured <u>and</u> discovery activities inside and outside. Despite the fairly high educational levels of Hispanic parents in our sample, the results indicated a preference for structured activities. An alternative explanation for the preference for inside activities in our study may be a seasonality factor. Ten out of the 15 family science events that we organized took place during the summer months of July, August, and September. In Texas, it gets very hot during these months and may cause parents to consider only inside activities with their children. Still, it is not clear why the highly educated Latinx parents in our study preferred structured activities that could be done inside.

While none of the Latinx parents in our study listed that they volunteered at their children's school with science, 86% of them were interested in assisting their children's school with science. This suggests that Latinx parents care about their children's science education and are willing to be involved. This is supported by Castaneda (2006) who found that Latinx parents do care about their children's education and Hernandez, Rana, Alemdar, Rao, and Usselman (2016) who found that Latinx parents who participated in family science activities wanted to keep doing the science activities at home.

Summary

Latinx parents, in our study, are more engaged with their children in free and structured science activities that can be done inside. This information may help school districts, administrators, and teachers to determine the best ways to implement family science programming in their schools or classrooms to better support their students' science education and to promote an interest in science. Latinx children who have their science learning supported and have an interest in science instilled in them may be more likely to pursue science in college and move forward to careers in STEM. This may help to decrease the gap in representation of Latinxs and Hispanics in the STEM workforce.

Limitations

It is important to note that only 18 Latinx parents participated in the study, which was a small sample size. In addition, Latinx parents that participated in our study volunteered to participate, which incorporates a self-selection factor into the study. Furthermore, because the Latinx parents in our study generally had higher levels of education than Latinxs in the general U.S. population, results from our study may not be generalizable to all Latinx parents. In the United States, the percent of Latinxs that have a bachelor's degree or higher is 18%, while 44% of the Latinx parents in my study have a bachelor's degree or higher (USCB, 2017b).

Even with these limitations in the study, the research findings are valuable. There are scarce studies in the literature regarding the types of science activities Latinx parents engage in with their children. Since parents are the most influential in the early development of children, it is necessary to better understand what Latinx parents are doing with their children in science. Through understanding Latinx parents, we are better able to indirectly support Latinx children's academic achievement in science and interest in STEM careers.

Future Directions

Future studies that explore the types of informal science activities that Latinx parents engage in with their children should have a larger sample and more representative of the Latinx population in the United States. To overcome this limitation, study sites should be selected that are visited more by Latinx parents. Also, partnering with a local school district in organizing family science events for parents and their children may decrease the effects of self-selection. It would be beneficial to have a larger sample size and reduced self-selection effects to gain a clearer picture of the types of informal science activities Latinx parents are doing with their children.

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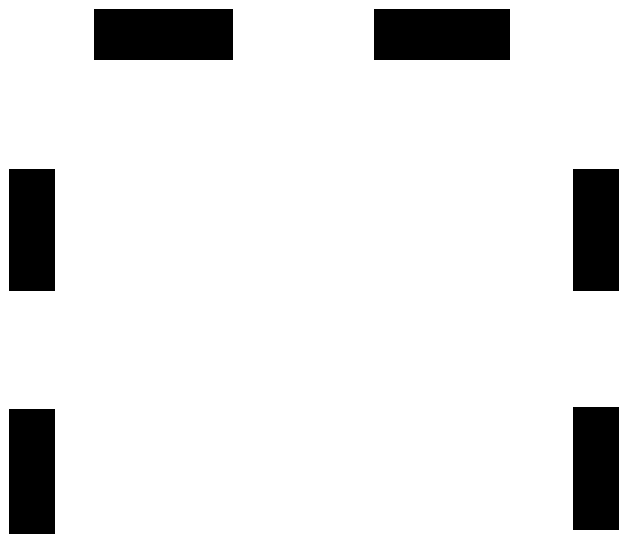
Appendix A

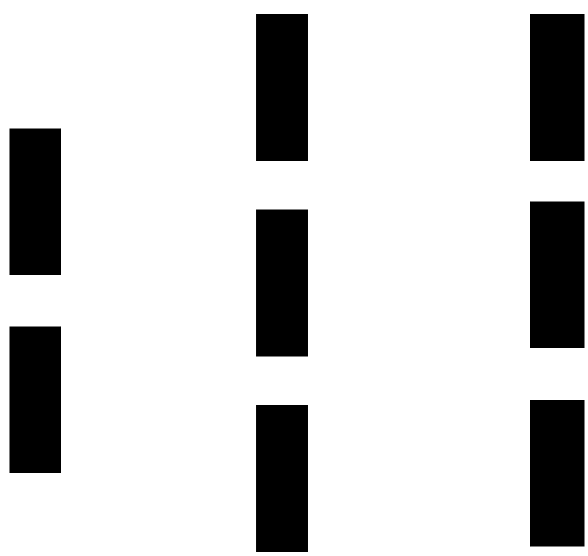
Family Science Event Set-Up

*Black rectangles represent tables

Pilot Study Family Science Event Set-Up



Revised Family Science Event Set-Up



Appendix B

Science Journals

My Science Journal!

____

Name

Magic Tape

1. Parent: Pull off two strips of tape about 4 inches long and fold the ends back on themselves to make a handle. Stick the two strips of tape down on top of the table.

   Parent and Child: Quickly rip off the strips of tape and hold them so that they hang down vertically. Slowly bringing the two strips near each other and observe what happens.

2. Parent: Pull off one strip of tape about 4 inches long and fold the end back on itself to make a handle. Stick the strip of tape down on top of the table. Pull another strip of tape of the same length and fold the end back to make a handle and stick this strip on top fo the strip on the table.

Parent and Child: Pull the two strips of tape off the table and hold them so that they hand down vertically. Quickly pull apart the two strips of tape and slowly bring the two strips near each other and observe what happens.

Appendix C

Informed Consent

Study Title: Increasing Parent Interest in Science and Parental Involvement for Latino Parents with Family Science Nights
Principal Investigator: Author **Co-Investigator/Faculty Advisor: Author**

This consent form will tell you why this study is being done. It will tell you why you are invited to participate. It will also tell you what you need to do to participate. You will be told about risks and difficulties that you may have while participating. We encourage you to ask questions at any time. If you decide to participate, you will be asked to sign this form. You will be given a copy of this form to keep.

PURPOSE AND BACKGROUND
This study will explore parent interest in science. Also, parent involvement in their children's science learning. You are asked to participate because you are the parent or guarding of a child in the 9-12-year age group.

PROCEDURES
If you agree to be in this study, you will participate in the following:

- A Family Science Night event
- A science attitude survey & event exit survey (10 min.)
- A take-home parent/guardian involvement questionnaire (10 min.)

Family Science Nights will be at the Public Library. They will be on Wednesdays from 6pm-8pm, June 28, July 5, July 12, July 26, August 2, and August 9. You will first complete the science attitude survey. After the Family Science Night, you will complete the exit survey. At the end of the event, you will be given a take-home questionnaire. This will be mailed back to us or returned during the Family Science Night event.

RISKS/DISCOMFORTS
The survey will have questions about your background. If you are not comfortable answering these questions you may leave them blank. If the survey or questionnaire makes you uncomfortable, you may leave them blank.

BENEFITS/ALTERNATIVES
The benefits to you are more awareness of science. Also, how to be more involved in your children's science learning.

EXTENT OF CONFIDENTIALITY
Your name will not be used in any written reports or publications. Information from paper documents will be converted to an electronic file. Then all paper documents will be shredded. The electronic file will be password protected and kept for three years. Then the electronic file will be deleted.

PAYMENT/COMPENSATION
You will not be paid for your participation in this study.

PARTICIPATION IS VOLUNTARY
You do not have to be in this study if you do not want to. You may refuse to answer any questions you do not want to answer. You may withdraw from this study at any time.

QUESTIONS
If you have questions about this study, you may contact Author.

This project 2017763 was approved by the University IRB on June 26, 2017. Questions about the study should be directed to the IRB Chair or to the IRB Regulatory Manager.

DOCUMENTATION OF CONSENT
I have read this form and will participate in the project described above. Its purposes, involvement and risks have been explained to my satisfaction. I understand I can withdraw at any time.

Printed Name of Study Participant	**Signature** of Study Participant	Date

Signature of Person Obtaining Consent	Date

Appendix D

Family Science – Parent/Guardian Involvement Questionnaire

Instructions: We would appreciate your completion of this questionnaire. You may choose not to answer questions that you are not comfortable with.

1. What ways are you involved with your child in science activities? Please explain.

2. What ways do you have conversations with your child about science? And how often? Please explain.

3. How comfortable are you doing science with your child? Please explain.

4. What sorts of things might help you feel more comfortable doing science as a parent/guardian? Please explain.

5. In what ways, if any, are you involved in the science being taught at your child's school? Please explain.

6. What is the biggest obstacle, if any, that prevents you from getting more involved in your child's science education? What might be able to help you overcome this obstacle? Please explain.

Appendix E

Modified for Summer 2018
Family Science – Parent/Guardian Questionnaire

Instructions: We would appreciate your completion of this questionnaire. You may choose not to answer questions that you are not comfortable with.

1. In the box next to each activity, mark the number of times you have done that activity with your child in the past week. If an activity you and your child have done is not listed please describe in the section called "other".

	Collected Rocks		Visited Aquarium		Visited Zoo		Worked on Science Activities Online		Observed Weather
	Observed Night Sky		Went on a Nature Walk		Used Physical Models		Worked on Home Science Projects		Visited library
	Went Camping		Went Fishing		Went for a Hike		Explored River		Birdwatched
	Attended Science Event		Attended Science Fair		Visited Museum		Watched Science Clips on YouTube		Taught Science in Homeschool
	Gardened		Talked About Science		Watched Science Documentary		Watched Science TV Show		Read Book on Science
	Researched Science Online		Worked on Science Activity Kit		Other:				

2. What obstacles, if any, prevent you from being more involved in your child's science education?

3. What might help you overcome any obstacles you listed above? Please explain.

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The Implementation of Reform-Based Standards in High School Chemistry Classrooms Influenced by Science Teaching Orientations

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ABSTRACT

Recent reform efforts have been adopted in the United States to reimagine student learning in science. Historical reform efforts have required teacher buy-in necessary for substantive change to occur. Using a mixed-method methodology, chemistry teacher progress in implementing the *Next Generation Science Standards* in Illinois and views about the purpose of science teaching and learning were explored in the context of teachers' curriculum design decisions. The results of this exploratory study suggest that standards alone are not sufficient for implementation. Chemistry teaching and learning appear to be partially mediated by a canon of knowledge that does not fully complement the standards teachers are asked to implement.

Keywords: science education, science curriculum, science instruction, educational change, teacher education, chemistry education

Introduction

Recent reform-based efforts that reimagine 21st century science teaching and learning are being adopted and implemented across the world. Since 2014, more than 20 states in the United States have adopted the *Next Generation Science Standards* (NGSS) and 24 others have developed their own standards based on the National Research Council's Framework for K-12 Education on which NGSS is also based (NSTA, n.d.). These standards are premised on the integration of content (disciplinary core ideas), scientific practice (science and engineering practices), and overarching ideas that transcend single, narrow topics (crosscutting concepts; nature of science) that are unified around real-life phenomena (NGSS Lead States, 2013a). Central to the idea behind this iteration of standards-based reform is the implementation of a model of science education that emphasizes deep connections and sensemaking over the breadth of content traditionally prioritized in curricula prior to their adoption (NRC, 2012).

The successful implementation of curricular reforms relies on several factors, but perhaps most important is the teacher buy-in that allows for transformation. Levin (2010) explains that "lasting school improvement will not come from the mindless adoption of someone else's plan or program but must involve thoughtful participation by many people within each school and community" (p. 742). In order to successfully adopt these standards, there must be a commitment to unifying reform-based approaches to teaching with a critical eye toward the role of content in secondary education. To do so requires a system of targeted professional development to develop the capacity of professionals asked to implement these standards in their classes (Banilower, 2019) and help minimize the potential for what Staw (1976) described as an "escalation of commitment" to curricular ideations of the past.

Implementing new standards requires teachers to transform their instructional approaches and contexts to reflect new expectations for student learning. As a result, it is critical to check in and examine the current status of these reform efforts in actual classrooms with practicing teachers. Pedagogical content knowledge (PCK) provides a useful framework for understanding the role that teacher decision-making and cognition play in the implementation of a standards-based reform. Using orientations to science teaching within the PCK framework to interpret results, this study explored Illinois secondary science teachers' reported implementation of a new science reform (NGSS) and its impact on enacted curriculum. Enacted curriculum in this case refers to the set of material resources as well as the content included or excluded from the cycle of learning experiences that teachers offer a given class. Core to this definition is the understanding that teachers play an active role in shaping curriculum rather than enacting that of others (Remillard, 2005). This study provides insight into the extent science teachers have adapted their practice to implement a new standards-based reform in ways that may reflect their own views. This study used chemistry teachers because of its relevance to physical science standards in NGSS and its prevalence as a core science class at the secondary level. These findings hold implications for future professional development and collaboration between secondary and tertiary science educators.

Literature Review

In this section, we make the case for why it is appropriate to study the implementation of NGSS in introductory chemistry courses in the state of Illinois and discuss some of the challenges to successful implementation of standards-based reforms.

The Link Between Chemistry Curriculum and NGSS

NGSS does not act as an explicit curriculum for discipline-specific science courses. In fact, these standards promote an integrated approach to science. Appendix K of NGSS offers model course maps for implementation of the standards, in part, based on "frequently taught courses of biology, chemistry, and physics" (NGSS Lead States, 2013b, p. 128). Nationally, introductory chemistry accounts for approximately 19% of all science courses taken at the high school level, second only to introductory biology at 29% (Smith, 2019), suggesting that, for many students, high school chemistry courses must align with NGSS if they are to meet these standards. Given that chemistry and biology account for nearly 50% of all science courses taken, it's likely that they represent the only opportunity that students will have to engage with most of the high school level physical science and life science standards, respectively.

The NRC (2012) framework for "PS1: Matter and Its Interactions" serves as the basis for much of the NGSS content that is presumed to be covered in a typical chemistry classroom. Students are expected to demonstrate proficiency based on each individual standard, known as Performance Expectations (PE), where they will explore relevant phenomena relating to broad disciplinary core ideas such as the structure and properties of matter, chemical reactions, and nuclear processes by using the science and engineering practices and crosscutting concepts. In doing so, students are able to dig deeper into concepts like the electronic structure of the atom, its characteristics and representation on the periodic table of the elements, and interactions of matter due to those properties as well as chemical reaction rates, bond energies, and the reversible nature of many chemical reactions in which matter is conserved (NGSS Lead States, 2013a; NRC, 2012). These same topics outlined in the *Next Generation Science Standards* (NGSS) are shared by the American Chemical Society (ACS) Guidelines and Recommendations for teaching middle and high school chemistry (2018). The successful implementation of these standards in a chemistry classroom would necessarily position these areas of physical science as central to student learning experiences and drive the curricular decision making of teachers. These align with the topics of this study (See Table 2).

The state of Illinois served as a sample population of teachers to explore the extent that NGSS is being implemented by adoptive states. Illinois was one of the lead states that participated in the development of these standards (NGSS Lead States, 2013a). For that reason, our study is situated in the context of Illinois as a sample that largely represents the work done throughout the United States. In the state of Illinois, there is a two-year science requirement (ISBE, 2016). As a result, many students are only exposed to science curriculum through a limited number of courses. Among high school graduates in the state of Illinois from the years of 2017-2019, no more than 20.68% had taken a course in physical science while 75.47% or more took introductory chemistry (ISBE, 2020) suggesting some NGSS must be covered in high school chemistry if students are to learn them. These physical science standards cannot reasonably be realized in a physical science course due to the limited number of students that take them; rather, they are allocated to introductory chemistry classes that are taken far more often. As a result, we will be focusing on chemistry classrooms as representative of the most common setting that Illinois students will be exposed to many of the physical science standards outlined in NGSS.

Teachers' Enactment of New Standards

The adoption of new standards represents the beginning of efforts to bring those changes to individual schools and classrooms. Central to this implementation is the work of teachers (Fullan, 2007). McLaughlin (1987) suggests that implementation begins, in earnest, once teachers are no longer concerned with the 'what' of the change, but the 'how'. In doing so, "...internal factors such as commitment, motivation, and competence dominate" (p. 174).

Often described as buy-in, the beliefs, perceptions, and values of teachers generally and in terms of the specific reform are essential in the process of implementation (Datnow et al., 2006). Transformation in teachers requires shifts in deeply-ingrained beliefs and understanding that result from personal reflection, experimentation, and cognitive restructuring which can take as long as three to five years to result in a new teaching practice to be fully implemented (Loucks-Horsley et al., 2010). There must be a fundamental change in people (the teachers) responsible for carrying out those reforms as each individual "...holds a set of assumptions that shape and are shaped by his or her values and actions" (Finnan, 2000, p. 6). Implementation of new standards operates on a similar constructivist learning paradigm that governs the very reform-based standards being explored.

Another factor relating to the implementation of reform efforts is teachers' view of students and their relation to the new instructional outcomes they are asked to achieve. Harris (2012) explains that the success of standards-based reform efforts hinges on "...unearthing deeply entrenched ideas about student deficits and intelligence" (p. 146). In addition to shaping views on pedagogy within the implementation of standards, teachers must confront the ways in which their perceptions of their students' capacity for learning shapes their choices in the classroom.

Lawrenz et al. (2005) explained how a previous standards-based reform effort was generally not sustainable due to "...external pressures, power structures [in the school] in relation to the reform, the availability of support, and the desire for change" (p. 11). Porter et al. (2014) use the context of recent Common Core reform efforts to suggest that as change efforts were increasingly perceived by teachers to be "duplicative, incorrect, or unfocused", the more likely it would be that the implementation was inadequate (p. 135). As potential agents for change, teachers have an outsized role in determining the success of a reform. The ability to engage successfully in "change" hinges on social learning and teachers' willingness to do something new, to develop "new meanings, new behaviors, new skills, and new beliefs" (Fullan, 2007, p. 97). Capturing information about the status of ongoing reform efforts requires insight into how teachers position themselves relative to the standards and whether their beliefs align with the goals of a reform effort. A teachers' pedagogical content knowledge (PCK) allows for insight into teachers' understanding and views relating to student learning.

Theoretical Framework

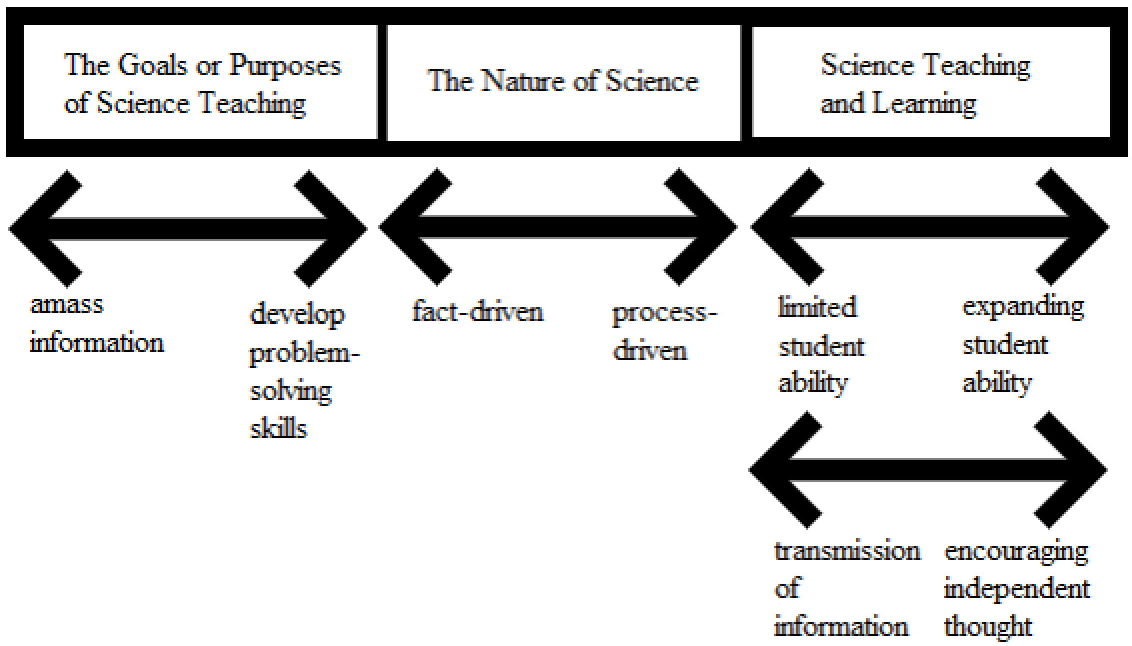
The shifts that teachers make to their personal cognitive structures as a result of efforts to begin implementing new standards in their classes can be understood in terms of their PCK. Previous studies have shown links between PCK and implementation of reform teaching standards (Wongsopawiro et al., 2016; Park et al., 2010; Cohen & Yarden, 2008). Since PCK impacts teachers' implementation of reform, we are using PCK, specifically their orientation toward science teaching, as a framework to examine their curricular choices and the way they've implemented NGSS in chemistry courses in IL.

This framework has served as a useful tool since Shulman (1986) presented a view of teacher proficiency (PCK) that represents the cognitive approaches and strategies that individual teachers use to integrate both their pedagogical and content knowledges and how they influence how students learn. In this model, teachers operationalize their content knowledge and pedagogical knowledge relating to science teaching, knowledge of curriculum, student understanding, assessment, and instructional strategies (Magnusson et al., 1999). Friedrichsen et al. (2011) elaborated on the existing model of PCK to include an explanation of an individual teacher's attitudes and beliefs relating to the teaching of science, described as their orientation towards science teaching, and described it's influence on the use of pedagogical and content knowledge in practice. Their clarification of the nature of orientations within the PCK framework suggests that teachers filter their views through lenses that relate the goals or purposes of science teaching, the nature of science, and science teaching and learning as they enact their PCK.

Friedrichsen et. al (2011) describe these orientations, in part, using a similar model offered by Lotter et al. (2007) that presents orientations along a series of continua and suggest that they each play a role in shaping the specific pedagogical and content knowledge teachers utilize in specific learning contexts. A modified view of teacher orientations using both the Friedrichsen et. al (2011) and Lotter et al. (2007) models is presented in Figure 1. These orientations effectively serve as amplifiers or mediators of student outcomes (Neuman et al., 2018). Ongoing professional development provides a necessary opportunity for teachers to reflect on and challenge their orientation(s) and actions in the classroom as they work to implement new standards and transform their practice (van Driel et al., 2001).

For this paper, we are using Figure 1 to interpret the ways in which teachers' orientations to science teaching influence curricular design and, eventually, in the enacted curriculum experienced by students.

Figure 1
Revised Model of Teacher Orientations in Practice



Note. Adapted from Friedrichsen et al. (2011) and Lotter et al. (2007).

Methodology

In order to understand the extent that topic-related curricular changes outlined by NGSS had taken place, individual chemistry teachers' reported implementations as enacted curriculum are explored using self-reported survey data. Time spent on various topics is used to understand teachers' perceived value of each topic as well as to compare the relative depth of topic coverage in their curriculum. This provides insight into the extent that a set of reform-based standards have been incorporated into everyday classroom experiences for students. Individual interviews are used to probe teachers' orientations such as the goals of teaching and learning science (chemistry) and what factors influence the time they allocate within their curriculum. Topic coverage and teachers' stated purposes for teaching and learning science and chemistry provide insight into the extent that current reform efforts (NGSS) have influenced the enacted curricula of individual science teachers within the state of Illinois in the United States.

This study was guided by the following research questions:

1. To what extent are the NGSS performance expectations (incorporating physical science disciplinary core ideas related to chemistry) integrated in Illinois chemistry classes five years after adoption?

2. How does a teacher's orientation to the teaching of chemistry, specifically their views of (a) the goals or purposes of chemistry (science) teaching and (b) science teaching and learning impact their curricular design choices?

We chose to use the PEs to organize the topics because the DCI's are either too general, (i.e. PS3.A: Definitions of Energy) or too specific (i.e. PS3.B: Conservation of Energy and Energy Transfer) for survey creation. By using the PEs, the traditional chemistry topics could be more clearly identified and allow for greater clarity in responses from teachers. Based on the purpose of the study, an explanatory mixed-methods design was used (Plano Clark & Creswell, 2010). With Institutional Review Board (IRB) approval, a self-reported online survey about Illinois chemistry teachers' current curricular practices five years after the statewide adoption of NGSS was administered using Qualtrics, an online survey platform. Once created, the survey was piloted by five practicing secondary chemistry teachers to obtain feedback relating to question clarity, ease of use, and survey length. Following this pilot, revisions were made, and the survey was distributed to potential participants that were reached through listservs and direct email. Survey data was collected throughout February 2019. The qualitative interview methodology allowed for the subsequent collection of data about the ways in which some teachers are similar or differ in their curriculum design and orientations to the teaching of chemistry.

Survey Instrument

The survey instrument used included demographics questions (e.g. school location, years of experience, etc.) as well as questions that explored the specific chemistry content taught and the instructional time spent on each topic within a typical school year (See Appendix A for complete survey instrument). Questions relating to content and instructional time were asked of teachers that taught introductory chemistry, honors chemistry, advanced, and/or Advanced Placement (AP) or International Baccalaureate (IB) chemistry. These topics were representative of the typical content that might constitute a portion of any potential chemistry course offered at the secondary level (Table 2 in the results has the list of topics and their alignment to the PEs). An option for "other" was offered for respondents that wished to provide additional content areas that were not specifically included in the survey instrument (See Appendix A). Using instructional time as a proxy for the level of incorporation of extent each topic in the course, participants were given the choice, as ordinal-level variables, of time spent on the topic as "0 Days", "1-2 Days", "3-6 Days", "7-10 Days", "11-15 Days", and "More than 15 Days". Responses were consolidated into "0-2 Days", "3-10 Days", and "11 Days or More" for clarity.

Questions about the extent that respondents felt their overall curricular goals were achieved, the ways in which local curricular collaboration occurs, and the changes made since the state's adoption of NGSS were also included. Additional questions asked teachers to identify chemistry topics that individual teachers most and least enjoyed as well as those that they would devote additional instructional time to if the school year were extended by several days.

Semi-Structured Interview

The qualitative interview utilized a script of approximately 12 open-ended questions in which teachers' specific orientations to the teaching of science and approach to curriculum design were explored in greater detail (See Appendix B for Interview Protocol). Questions were, in part, derived from previous research relating to teacher beliefs and orientations (Luft & Roehrig, 2007). Other questions were designed to elicit specific information about enacted curriculum in teachers' classrooms as well as any influence felt by new curricular standards.

Participants

The survey was distributed to Illinois chemistry teachers using state chemistry teacher organization and state science teacher email listservs, direct solicitation, and existing email contacts with encouragement to forward it to other chemistry teachers. Respondents that completed the survey were eligible to submit their email address for an opportunity to win an Amazon gift card. A total of 128 Illinois chemistry educators responded. Survey responses were completed by teachers of introductory chemistry (94.5%), advanced chemistry (19.7%), and AP/IB chemistry (24.4%). Of the respondents, 30.5% taught at schools where chemistry was required and 37.2% taught only chemistry. Respondents rated their familiarity with NGSS on a Likert-style scale with a 5 being expert-level, 59.0% of all respondents rated themselves as a 4 or 5 while only 8.6% rated themselves as a 1 or 2. Table 1 provides additional demographic information about participants' teaching experience and educational attainment.

Table 1
Survey Participant Demographic Information

Demographic	Value	Frequency
Setting	Rural	31.3%
(N=128)	Suburban	57.0%
	Urban	11.7%
Degree Type	Bachelor's	23.6%
(N=127)	Master's	72.5%
	Doctorate	3.9%
Taken Graduate Course in Chemistry	Yes	50.8%
(N=128)	No	49.2%
Teaching Experience	0-3 Years	18.8%
(N=127)	4-10 Years	28.9%
	11+ Years	52.4%
Familiarity with NGSS	Low (1-2)	8.6%
(N=117)	Moderate (3)	32.5%
	High (4-5)	59.0%

Interview participants were volunteers that self-identified and chose to provide their name and contact information following the completion of the survey instrument in the first phase of the study. Selection of individual teachers for interview was based on convenience sampling (Creswell, 2008). Because far more volunteers were willing to participate in the interview than was possible to interview, individual participants were selected using maximal variation sampling to ensure equal representation from rural, suburban, and urban schools as well as from early-career, mid-career, and veteran teachers as well (Plano Clark & Creswell, 2010). After receiving a completed informed consent form, interviews were completed over the telephone and digitally recorded.

Data Analysis Procedures

Survey data was analyzed using the SPSS software package. Data analysis techniques including descriptive statistics and Pearson chi square to determine if any of the findings were statistically significant at the $p < 0.05$ level or lower (Plano Clark & Creswell, 2010). Interview data recordings were transcribed verbatim and, initially analyzed using a preliminary exploratory analysis (Creswell, 2008). Identified text segments were initially coded for themes using NVivo based on relevance to each research question and their relation to teacher orientations. Initial coding themes were developed based on the patterns of responses for clusters of related code such as: goals and purposes of teaching chemistry (e.g. college preparedness or skill focus) or views of teaching and learning science (e.g. student ability, relevance of content, etc.) (Corbin & Strauss, 2015). As part of an explanatory mixed-method design, the interview portion was used to refine and contextualize results from the survey portion of the study and further develop established themes (Plano Clark & Creswell, 2010). Reported findings and quotations are presented using pseudonymous initials in order to preserve participant anonymity.

Limitations

There are several limitations for this study which should be mentioned. It relies on self-reported data of classroom practices from Illinois chemistry teachers which cannot be guaranteed to be entirely reliable. Focus questions on the survey dealt primarily with content and, as a result, bias the responses toward DCIs over SEPs or CCCs. Interpretations about the extent of implementation of phenomena-based instruction or SEPs or CCCs would not be appropriate given the scope of this study.

Results

The study provided insight into how Illinois chemistry teachers are integrating NGSS into their introductory chemistry classes. First discussed below are survey results detailing NGSS PE coverage in introductory chemistry. Then, the teacher interview results detailing orientations to the teaching and learning of science and chemistry as well as the ways in which teachers individually (and in collaborative groups) approach curriculum design and revision are shared below.

Integration of Relevant NGSS PEs in Introductory Chemistry

Teachers were asked to reflect on the amount of time (in days) spent on specific content (DCI, aligned to each PE) taught in the introductory chemistry course(s) they were responsible for. Not all PEs were covered in the same amount of class time (See Table 2). NGSS-related topics such as bond energy, kinetics, equilibrium, and nuclear chemistry all tended to receive two or fewer days of attention in the chemistry classrooms of teachers surveyed. Other topics found in NGSS, such as stoichiometry, appeared to be addressed much more extensively as 64.5% of teachers reported dedicating 11 days or more of class time to it. Topics not explicitly included in the standards such as atomic structure, nomenclature, and predicting/classifying chemical reactions were reported to receive more class time as well. For example, 44.4% of classrooms spent 11 days or more teaching nomenclature, which would rank higher than any of the NGSS-aligned topics except for only chemical bonding and stoichiometry.

Table 2
Time Spent on Topics in Introductory Chemistry

NGSS Performance Expectations (PEs)	Topic Name	0-2 Days	3-10 Days	11 Days or More
HS-PS1-1 HS-PS1-2	Periodic Trends	12.2%	63.3%	24.5%
HS-PS1-2	Chemical Bonding	2.2%	48.9%	48.9%
HS-PS1-3	Intermolecular Forces	44.9%	50.6%	4.5%
HS-PS1-4	Bond Energy	67.4%	28.1%	4.5%
HS-PS1-5	Kinetics	72.7%	25.0%	2.3%
HS-PS1-6	Equilibrium Chemistry	58.6%	37.9%	3.4%
HS-PS1-7	Stoichiometry	4.4%	31.1%	64.5%
HS-PS1-8	Nuclear Chemistry	55.6%	33.0%	11.3%
HS-PS2-6 HS-LS1-6	Organic Chemistry	84.1%	14.8%	1.1%
HS-PS3-4	Calorimetry	44.4%	40.0%	15.5%
N/A	Acids & Bases	37.8%	51.1%	11.1%
	Atomic Structure	1.1%	46.6%	52.2%
	Gas Laws	33.3%	36.6%	29.0%
	Nomenclature	6.7%	48.9%	44.4%
	Predicting Products of Chemical Reactions	5.5%	55.5%	38.9%

Note. N/A means that the topic is not directly applicable to an NGSS PE.

In more than 40% of the teachers' introductory chemistry classrooms, eight of the identified physical science PEs that align with typical chemistry content (out of 11) were given two or fewer days of class time while many were reported to be not covered at all. For example, bond energy and kinetics were each covered for two days or less in more than 67.4% of introductory chemistry classes surveyed.

Survey respondents were also asked to rank their three most and three least favorite subjects to teach in their introductory chemistry course as well as what topic they would spend additional time on if the school year were extended by a few days (See Table 3). Stoichiometry, gas laws, and predicting/classifying products of chemical reactions were reported to be among the most enjoyed by respondents, receiving a vote from no fewer than 35.0% of respondents, each. At the same time, bond energy (a topic included in NGSS) was the most consistently disliked of all topics with 41.6% of respondents indicating their it was among their least favorite topics.

Table 3
Attitude Toward Topics in Introductory Chemistry

NGSS Performance Expectations (PEs)	Topic Name	Most Enjoyed Topics (Top 3)	Least Enjoyed Topics (Top 3)	Would Spend Additional Time (if available)
HS-PS1-1 HS-PS1-2	Periodic Trends	12.8%	23.0%	0.8%
HS-PS1-2	Chemical Bonding	15.4%	4.4%	4.2%
HS-PS1-3	Intermolecular Forces	12.8%	18.6%	7.6%
HS-PS1-4	Bond Energy	25.8%	41.6%	20.2%
HS-PS1-5	Kinetics	9.4%	14.2%	9.3%
HS-PS1-6	Equilibrium Chemistry	17.9%	18.6%	22.0%
HS-PS1-7	Stoichiometry	48.7%	11.5%	9.3%
HS-PS1-8	Nuclear Chemistry	18.8%	18.6%	17.8%
HS-PS2-6 HS-LS1-6	Organic Chemistry	3.4%	13.3%	22.0%
HS-PS3-4	Calorimetry	11.1%	14.2%	9.3%
N/A	Acids & Bases	24.8%	9.7%	35.6%
	Atomic Structure	8.5%	15.0%	0.8%
	Gas Laws	35.0%	3.5%	17.8%
	Nomenclature	12.0%	23.0%	0.0%
	Predicting Products of Chemical Reactions	35.9%	7.1%	0.8%

Note. N/A means that the topic is not directly applicable to an NGSS PE.

Responses for time spent on each topic in introductory chemistry were compared using Pearson chi square analysis for differences between school setting, teacher level of education, years of teaching, advanced coursework in chemistry, and level of chemistry taught (See Appendix C for complete statistics). Few relationships between the variables were shown to be statistically significant ($p < 0.05$). Significant relationships were found between time spent on bond energy and setting ($X^2_{(2)}$

= 10.197, p = .037), time spent on gas laws and having taken a graduate course in chemistry ($X^2_{(1)}$ = 6.497, p = .039), time spent on intermolecular forces and also teaching AP/IB chemistry ($X^2_{(1)}$ = 6.207, p = .045), and time spent on organic chemistry and setting ($X^2_{(2)}$ = 12.051, p = .017). No significant relationships were found between time spent on a given topic and any other variables tested. Because only four of the test statistics were significant out of the 105 tests run in the crosstabulation, it would be reasonable to assume that any significant results were not practically significant.

Table 4

Partial List of Codes, Definitions, Sample Responses, and Frequencies for Answers to: What significant changes, if any, have been made in your school's chemistry curriculum as a result of the state's adoption of the Next Generation Science Standards (NGSS)?

Code	Definition	Sample Response	Frequency
		State of Chemistry Curriculum	
Changes Made	Curricular changes have been made to account for the expectations of NGSS	"We have cut down on ALOT of content and really focus on students 'doing' science…rather than knowing about science" "We redesigned our Periodic Table unit to be fully 3D learning"	73.1%
Changes in Development	Curriculum is still being changed to meet the demands of NGSS	"Currently working on revising the science curriculum" "Our district is currently doing a science curriculum review to align to NGSS"	7.7%
No Changes Made	Curriculum has not undergone significant change following the adoption of NGSS	"None…curriculum leaders have no intention of actually changing the curriculum" "Have had to fight to maintain the integrity of [existing] chemistry curriculum…"	19.2%
		Types of Curricular Changes Made: Content	
Added Content	Curriculum was modified to add content that had not been part of the curriculum prior to NGSS	"We also added topics like nuclear chemistry and reactions rates…" "Some topics, like kinetics and equilibrium, are introduced earlier than before (intro chem vs. AP)"	14.1%
Removed Content	Curriculum was modified to remove content that had previously been part of the curriculum prior to NGSS	"Eliminating concepts such as sig figs, electron configuration…" "…I have ditched some of the units of tradition…"	21.8%
Emphasized Phenomena	Curriculum was modified to be guided by an observable event for each unit of instruction	"Using phenomena to drive the curriculum" "…most units are driven by a real-world application and examples from every day life are used when possible"	3.9%
Using Other Curricula	Curriculum created elsewhere was used as the basis for school curriculum	"We use the chemistry modeling curriculum from AMTA" "I switched to the Chemistry Modeling curriculum 5 years ago…"	5.1%
		Types of Curricular Changes: Emphasis	
Prioritizing Skills	Curriculum has changed to allow for more opportunities for student to develop skills beyond content	"Science and engineering practices and crosscutting concepts are more of a focus" "More emphasis on skills and reasoning/justification"	32.1%
Student Centered	Curriculum has changed to allow students more control of their learning and rely less on direct instruction	"Adapted to more collaborative and discussion moving away from lecture-based classroom dynamics" "I have designed more opportunities for students to present, collaborate, and communicate their findings in class" "…make the class more student-centered and less teacher-centered"	9.0%
		Types of Curricular Changes: Assessment	
Assessment	Changes have modified the way(s) that students are able to submit evidence of their learning	"More…3D assessments" "[Changed] expectations of what students should be 'producing' to demonstrate mastery of a standard"	3.9%

Note. Frequency percentages calculated from N= 78 total responses.

Teachers were asked to share any changes they've made to their curriculum as they've begun implementing NGSS in their classes. Table 4 shows a list of all the codes, definitions, sample responses, and frequencies for responses to a survey question asking teachers to report any significant changes (if any) that their chemistry curriculum has undergone since adoption of NGSS. 80.8% of all responses (N=78) reported that their curriculum had undergone some degree of change—or that changes were ongoing while 19.2% indicated that their curriculum had not changed as a result of NGSS. An example response of those that said their curriculum had not changed:

> *We have had to fight to maintain the integrity of chemistry curriculum in spite of the misguided attempt to enforce the minimum standards outlined in NGSS for Chemistry! We shouldn't gut a great curriculum just because concepts are not given enough depth in NGSS.*

Content was added to curriculum in 14.1% of responses while content had been reportedly removed in 21.8%. Skills such as critical thinking using SEPs and CCCs were reported to receive greater emphasis in the curriculum of 32.1% of responses.

Goals and Purposes for Teaching Chemistry: Impact on Curricular Design

Table 5 provides a list of all the codes, definitions, and sample responses from the interview analysis. Interviewees (N=9) were asked about the purpose for teaching or learning chemistry (a part of their orientation, see Figure 1) and codes emerged in which respondents viewed introductory chemistry as either preparation for future chemistry coursework (primarily at the collegiate level) or as an opportunity to develop generalizable critical thinking skills.

Table 5

Partial List of Codes, Definitions, and Sample Responses from Interviews

Code	Definition	Sample Response
	Goals and Purposes for Teaching Chemistry	
College Preparation	Exposure to large amounts of information and content typically associated with an introductory undergraduate chemistry course	"I try to get them enough information and I pound it on them" "If you have a college chemistry class these are some things that you will feel more supported when you get to that content because you have seen it before"
Skill Development	Development of a personal skillset or ability to think critically and apply science reasoning to larger problems or contexts	"…to make a well-informed person…making informed choices" "…experimenting, trying things, fixing, evaluating…" "…to really get the kids…prepared for jobs that aren't around right now"
	Views of Teaching and Learning Science	
Student Ability	Innate characteristics of students or groups of students that drive instructional decisions	"…the kids that don't get it are never going to get it" "We should be teaching to the higher-level student, not tailoring everything to the lower-level student"
Relevance of Content	Individual teacher enjoyment of topics of view of its role within a coherently designed chemistry class	"I'm going to teach it because it's a standard part of a chemistry course anyway and I don't care what NGSS calls it, I'm just going to do it" "I'm not going to go full fling into something that leaves out major ideas that are essential for any chemist"
Perception of Standards	Personal philosophy or interpretations of the extent that NGSS should be used in curricular design	"I'm quite content if my 10th graders have the kind of understanding that NGSS is listing as a 7th grade concept" "I've been picking and choosing NGSS standards that fit my lesson"

For six of the nine interviewees, the primary purpose of taking a chemistry course was to prepare for a future chemistry course at the collegiate level. For example, MD explained:

> *I don't focus a lot on the theory too much, on the background of why. I just focus on the task that we need to complete so that when they leave my classroom, they should be able to go to college and enter a chem 101 class and feel comfortable.*

For the remaining three of the nine interviewees, the purpose of taking a chemistry course fell in line with a need to prepare for a lifetime of employment and/or the development of generalizable skills (See Table 5). Personal decision making and problem solving were cited as the larger goal behind learning chemistry at the secondary level. For example:

> *Maybe 10 years from now or 10 days from now they won't remember exactly what we did in class but the skills of them learning those ideas of being able to look at data and critically analyze it and figure out something that they do not necessarily see with their naked eyes is a very important skill. (JE)*

As another example:

> *I think the purpose of science education is to get students thinking critically about the world around them and doing that through a scientific lens. So being able to analyze data and creating meaning from it...not just in the classroom but also big picture so that they're developing these skills so when they go out into the world and they have these graphs and charts and data sets to analyze they can think critically about what those numbers mean and they have skills to interpret the information. (HP)*

Using scientific reasoning and developing the ability to apply critical thinking to a problem were clear priorities for each of the three teachers that appeared to prioritize development of science process skills in their respective chemistry classes.

Views of Teaching and Learning Science: Impact on Curricular Design

Another part of orientations includes teacher views about the best ways that teachers teach and students learn science. As interviewees (N=9) were asked about their understanding of their role as a teacher, their students' roles as learners, and how students best learn science, codes relating to student ability, relevance of content, and perception of standards emerged (See Table 5).

Three of the interview participants specifically suggested that their perception of their students' capacity for learning chemistry content played a role in determining the depth and breadth of the curriculum as well as their instructional approach. For example, TJ explained that "...the kids that don't get it are never going to get it". A different teacher, MD, described their frustration with having students that they viewed as "pretty low overall" and explained that they don't view many of their students as being capable of what the teacher viewed as "higher-level" work because they felt that they had to "hold [a student's] hand constantly". Similarly, RS wondered:

> *As high schoolers, do you want to do a worksheet you can do or do you want to think? There's always the worksheet that they can do. They just want to answer their questions, get the A, and go. That's not true to all of them, but you notice those more when you are on a phenomena focus because those kids are like 'WHAT WHY?!' so these are things I think are way more fun the way that we're doing.*

Interviewees overwhelmingly cited the relevance of content that they felt constituted a chemistry course as the basis for their enacted curriculum. Five teachers cited essential ideas and concepts that existed prior to the development of NGSS as the basis for a chemistry class of any type. For example, LR wondered:

> *How do you have a chemistry curriculum with standards that don't mention the word moles...I mean that doesn't make sense, so there's every chemistry teacher I know whenever I talk to them about this, what they are doing to sort of, take the best of NGSS and incorporate that into their classroom, but they are not going to give up the things that they know in their heart are good chemistry concepts, but just don't happen to be represented in NGSS, you know?*

Of those, three specifically explained that several specific performance expectations (PEs) and disciplinary core ideas (DCIs), such as equilibrium or kinetics, were not included in their curriculum because those PEs or DCIs didn't align with their view of what a chemistry course ought to be.

Six of the participants, including all five from the preceding paragraph, referenced their personal interest or desire to teach certain topics over others as a significant reason for spending a given amount of time on a specific topic. GP gave an example of this by explaining that "I really like stoichiometry because I like the numbers. I like being able to do the calculations and stuff like that". Another example involved making sure that their students are engaging in ideas that have practical relevance to students' lives beyond academics. LR explained:

> *I've started to focus...on climate because I just don't think, as a science teacher, I can't just teach my class and call it a day anymore—and that's a radical shift for me. I used to just bounce all around the map with stuff that I did in those segments of my teaching, but I just feel like as a society, we science teachers that owe it to the rest of society to kind of impress upon the new generations that like 'No! This is the most urgent thing on the planet!' and we need to be thinking about it more.*

Among the ways that participants described topics of interest, four specifically cited their own personal philosophies or their own interpretations of the standards as a justification for their approach to what topics should be included in their curriculum following the state's adoption of new standards in 2014. Two examples of this are:

> *This textbook just goes to the basics and that's really all I incorporated. I never did nuclear prior to when NGSS came up because there's a big stipulation on there on nuclear on doing half-life and things like that so that's when I incorporated it. (MD)*

> *There's things that maybe I spend time on that I shouldn't according to NGSS. I spent some time on significant figures...something that I feel like is important and then I know that kids in my introductory chemistry have not been exposed to significant figures so I feel like it's important in lab and to measurement to be able to do stuff like that. So that is stuff that I spend time on that maybe I shouldn't according to NGSS but I feel like I don't get through all the material that I want to in chem 1. (GP)*

Discussion

Evidence from this study suggests that the process of implementing NGSS in chemistry classes across the state of Illinois remains a work in progress. Even though they claimed strong knowledge of NGSS, teachers' self-reported survey responses suggest that many topics mandated by NGSS such as bond energy, equilibrium chemistry, kinetics, nuclear chemistry, and organic chemistry are not being integrated into teachers' enacted curricula (Table 2). Similarly, topics such as nomenclature and predicting products of chemical reactions are covered far more extensively despite their lack of explicit inclusion in the state standards. The only topic covered explicitly in NGSS that received comparable attention is stoichiometry; more than 60% of introductory chemistry classrooms report spending 11 or more days covering this topic. Three of the PEs (bond energy, equilibrium chemistry, and organic chemistry) that ranked among the least in time spent in introductory chemistry classrooms were selected as topics that teachers would consider allocating additional class time toward if the school year were unexpectedly extended by several days. This indicates that many teachers may be aware that they may not be adequately covering some of these topics and view themselves as having to make choices in coverage.

Responses were consistent between different subgroups (school setting, teacher level of education, years of experience, etc.) as evidenced by the lack of statistically significant differences in responses. This suggests that it is likely representative of the PE coverage in the variety of chemistry classroom environments throughout the state of Illinois. These results mirror those of a similar study done with Iowa teachers prior to the adoption of NGSS (Boesdorfer & Staude, 2016). Evidence suggests that many teachers have made or are continuing to make changes to their curricula as a response to new standards (Table 4). Despite that, it seems that the adoption of new standards alone has not caused a substantial shift in topics covered in introductory chemistry courses across the state. An Illinois teacher, JE, in an interview response may been hyperbolizing a bit when explaining that "if anybody says they are doing NGSS in the classroom...I don't think they are", but that sentiment may not be as far from reality as it might seem. As with past reform efforts (Datnow et al., 2006; Finnan, 2000; Fullan, 2007; McLaughlin, 1987), these results suggest that the enacted curricula of individual teachers are influenced by more factors (such as orientations) than just the existence of state standards.

Based on interview responses, six out of nine participants believe that goals for teaching and learning science—and chemistry in particular—emphasizes the preparation of students for rigorous study in college. Using Figure 1, the purpose of teaching or learning science can be viewed along a continuum from amassing information to developing problem-solving skills (critical thinking). Two-thirds of participants positioned themselves closer to the amassing information end of the continuum despite the fact that research suggests that amassing information is not the most appropriate way to prepare students for collegiate-level work and is less important than science reasoning (Cracolice & Busby, 2015; Lawrie et al., 2019). This is reinforced by studies (Tai et al., 2005; Tai, et al., 2006) that show that a student's high school chemistry experience has an impact on their success at the collegiate level, but that the secondary chemistry teachers' view of what is important for success do not match those of university professors that teach introductory chemistry (ACT, 2009, 2012, 2016).

These orientations towards science teaching seem to be impacting the decisions of teachers more than the standards, themselves. This is problematic for introductory classes taken by most high school students and includes those that intend to pursue collegiate study as well as those who don't. According to the Illinois State Boarded of Education (2019), 26% of all high school graduates in Illinois do not plan to enroll in postsecondary education. For non-college bound students, these introductory classes may not be as welcoming, or the covered concepts perceived to be inherently for other students. This gap in perception suggests a need to fundamentally question the collective wisdom of the canon of knowledge that appears to drive chemistry instruction in high schools. Additionally, there appears to be a need for more clear communication between secondary and post-secondary chemistry teachers.

Attempts to understand the extent that NGSS has been implemented in chemistry classes across the state of Illinois must be understood in context of the curriculum enacted in classrooms. In response to the questions about the various considerations used to revise or design their chemistry curricula, teachers appear to be influenced by their individual orientations in context of their views of teaching and learning in science. Teacher views about the best ways to teach and learn in science classes can be viewed through a lens of student ability (limited ability vs. capacity for expanding ability) and what constitutes learning (information is transmitted vs. independently constructed) (See Figure 1). Interview responses from three participants indicated a tension between both views of student capacity in curriculum design (See Table 5). One teacher argued that students they identified as "higher-level" are the more appropriate target for instruction than those they describe as "lower-level". Rather than tailor instructional sequences to be accessible to all students, it seems that some teachers may solve the problem presented by certain concepts in NGSS that require what they believe to demand a higher cognitive load by simply avoiding those concepts altogether.

Five of the nine interview participants specifically described their view that it was important to transmit a certain body of information to students, often described using "Chemistry" as a proper noun to describe the material they believed to be essential for students. Others described a willingness to deemphasize topics that fall within the traditional introductory chemistry canon (such as nomenclature) in effort to better align with the expectations of NGSS. This reinforces the idea that the implementation of NGSS is incomplete and mediated, at least in part, by a canonical body of chemistry knowledge. This is referenced repeatedly by interviewees who believe that NGSS is deficient in some ways because they feel that it "leaves out major ideas" or that teachers feel they need to simply "pick and choose" what standards fit their existing lessons. These results mirror that of previous scholarship on individual teachers' orientations to the teaching and learning of secondary chemistry (Deters, 2003) and science, generally (Friedrichsen et al., 2011).

The results of this study suggest further discussion and professional dialogue must take place in order to help teachers transform their science teaching orientations (goals of teaching and learning science, nature of science, and science teaching and learning). Questioning the purpose of an introductory science course like chemistry is an essential step—are these courses simply an opportunity to learn science through a chemistry-centric lens or do they offer an opportunity to preview some of the content frequently taught in introductory science courses at the collegiate level? In today's educational landscape, it appears more critical than ever to be able to offer a compelling reason for what students are asked to learn. Practitioner journals, professional conferences, and regional professional learning committees could be ideal opportunities to work with colleagues to challenge each other's underlying assumptions and presumptions that may or may not serve our students' best interests.

Conclusion

The evidence presented in this study shows that the enacted curriculum of Illinois introductory chemistry teachers does not align well with the goals (PEs) of NGSS. Much of the chemistry content outlined in NGSS appears to be underemphasized in comparison to other topics that fall outside of those standards. As a result, students may be leaving their high school science classrooms without sufficient opportunities to develop understanding of core ideas and achieve the related goals in the standards. Evidence from this study suggests that the enacted curriculum, which is not aligned with NGSS, appears to be driven more by individual teachers' orientations to and views of teaching and learning of chemistry than by the state standards alone. These orientations have a mediating influence on teacher decision making, which seems to be reinforced through the widespread view that the goals of introductory chemistry require the preparation of high school students for postsecondary chemistry coursework. These findings mirror those of previous studies of the implementation of reform-based standards (Roehrig & Kruse, 2005; Roehrig et al., 2007; Lowe & Appleton, 2014; Veal, et al., 2015). It appears that views about the purpose of teaching and learning science as well as the existence of a canon of chemistry knowledge continue to exert a profound influence on the ways in which secondary teachers shape their curriculum. While the implementation of reform-based standards has clearly not failed in Illinois, full implementation requires the focus of ongoing professional development to help shift teachers' orientations and engage in critical discourse and collaboration amongst professional communities already eager to help students succeed.

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Appendix A

Survey Questions

1. How would you classify the school you teach in?
2. Approximately how large is your school's population?
3. Are all students at your school required to take at least one year of chemistry?
4. How many years (including this year) have you been teaching?
5. How many years (including this year) have you been teaching chemistry?
6. What is your highest degree?
7. In what are of study have you earned a bachelor's degree? (Check all that apply)
8. Have you taken graduate-level courses in chemistry?
9. Which of the following chemistry classes are you currently teaching? (Check all that apply)
10. During the current school year, what classes do you teach besides chemistry?
11. What classes have you taught in the past that you are not teaching in the current school year?
12. In your Introductory or First-Year Chemistry classes, how much time do you spend (in a typical year) on each of the following concepts (including assessment and any other instructional time)?
13. Question 13 repeated for Honors (Introductory or First-Year), Advanced (Second Year or Beyond), and/or Advanced Placement (AP) or International Baccalaureate (IB) Chemistry classes (if applicable).
14. Please select the three (3) chemistry topics you enjoy teaching the most.
15. Please select the three (3) chemistry topics you enjoy teaching the least.
16. In a typical year, do you make it through the entirety of your school's chemistry curriculum?
17. If your school year was extended by 5-7 days, what two (2) topics would you be most likely to spend the additional time on in your chemistry class?
18. How much control do you have over your school/district's chemistry curriculum?
19. How familiar are you with NGSS?
20. Is your school or school district's curriculum currently aligned to NGSS?
21. How often do you (or your team) revisit your existing chemistry curriculum and make revisions (if needed)?
22. Are you satisfied with the way that your building stakeholders collaborate on chemistry curriculum?
23. What significant changes, if any, have been made in your school's chemistry curriculum as a result of the state's adoption of NGSS?

Appendix B

Semi-Structured Interview Question List

Note: Questions a, b, etc. only used as necessary.

1. What do you believe is the purpose of science/chemistry education?
2. How do you describe your role as a teacher?
3. What should students know and be able to do when they learn science?
1. In your classroom, how do you decide what to teach and what not to teach?
    a. How do you know when your students understand?
    b. How do you decide when to move on to a new topic in your classroom?
    c. How do your students learn science best?
    d. How do you know when learning is occurring in your classroom?
2. What level of chemistry do you teach?
3. Do you typically get through your entire chemistry curriculum in a given year?
    a. If yes, what do you use the additional time for?
    b. If no, how do you make modifications at the end of the year?
4. What topic(s) do you spend the most time on? The least?
5. Tell me about your unit on ______________.
6. Of the content that you teach, what topic(s) take students the longest time to master/understand?
    a. What makes those topics so difficult?
    b. How have you changed your instruction over the years to attempt to address this?
7. (For Veteran Teachers) How has your curriculum changed over the years?
    a. Are there any topics that you did not teach prior to NGSS that you now teach?
        i. If you had your choice, would you stop teaching it?
    b. Are there any topics that you taught prior to NGSS that you no longer teach?
        i. If you had your choice, would you still teach them?
8. At the end of the year, are there any topic(s) that you don't have time for?
    a. Why?
    b. What adjustments do you make as you finish the year?
9. Is there anything else you would like to say about your curriculum or teaching?

Appendix C

Table 1

Chi Square Test for Relationships between Time Spent Teaching Topics in Chemistry and a Variety of Variables

Topic	Setting	Degree Type	Teaching Experience	Graduate Course in Chemistry	Also Teach Honors Chemistry	Also Teach Advanced Chemistry	Also Teach AP/IB Chemistry
Acids & Bases	1.663	8.818	7.742	0.156	1.369	2.516	2.471
Atomic Structure	2.565	12.489	13.350	1.342	0.281	0.310	0.853
Bond Energy	10.194*	9.222	11.117	0.519	1.109	1.414	1.025
Calorimetry	2.498	13.649	9.668	0.392	0.282	1.054	0.686
Chemical Bonding	6.589	7.300	7.398	2.124	0.753	0.686	0.377
Equilibrium Chemistry	4.934	4.860	5.100	1.284	5.288	4.199	0.859
Gas Laws	1.653	11.710	11.980	6.479*	0.682	1.133	2.891
Intermolecular Forces	5.361	3.292	7.201	1.078	0.499	2.468	6.207*
Kinetics	2.863	9.051	13.817	0.017	0.945	1.124	0.542
Nomenclature	4.439	4.668	10.786	2.338	1.209	0.741	0.521
Nuclear Chemistry	4.041	9.703	7.520	3.659	2.839	2.313	0.306
Organic Chemistry	12.051	7.206	8.861	1.225	0.450	2.381	3.150
Periodic Trends	2.575	9.819	6.962	0.807	4.998	0.363	0.274
Predicting Products of Chemical Reactions	7.797	13.100	5.113	0.067	3.371	1.645	2.127
Stoichiometry	7.408	6.407	7.276	4.085	5.134	1.874	0.306

*$p < .05$.

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How Much is Lost? Measuring Long-Term Learning Using Multiple Choice Tests

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ABSTRACT

This work proposes a new approach for measuring long-term conceptual knowledge based on the after-instruction evolution of students´ answers to a research-based, multiple-choice, single-response test. The method allows for a quantitative determination of the fraction of students that, after instruction, attain long-lasting and temporary learnings, as well as those that did not learn. It also provides a plausible value of the experimental error. The method has been applied to analyze data obtained from a group comparison quasi-experimental design, in which two intact, equivalent high school classes have been subjected to two different instructional approaches. Conceptual knowledge of the subject, simple resistive electric circuits, was measured through the administration of the multiple-choice test DIRECT at three different times: before and immediately after instruction and one year later. Results indicate that the fraction of students achieving long-term learning is about four times larger in the group that followed active-learning activities, compared with the class that followed traditional instruction; drastically decreasing the no-learning group. The proposed method is relatively simple to implement and to interpret, providing more in-depth information, with higher accuracy and detail than the usual pre- and post-instruction data analysis. Some suggestions for complementary studies and to improve instruction are also given.

Keywords: MCSR tests, long-term learning, conceptual knowledge, electric circuits, tutorials

Introduction

While long-term learning is a central objective of instruction, it is well known to teachers and researchers that students lose some knowledge with time (Bernhard, 2001; Pollock, 2009). Therefore, regular post-instruction evaluation, which includes a certain (usually unknown) fraction of temporary learning, is not an accurate measurement of long-term, post-instruction knowledge. Although this fraction of labile knowledge is often useful to students for passing course examinations, especially in traditional instruction, after a certain time it disappears, becoming no longer available for future use, including to support further learnings.

Long-term learning studies are not abundant in literature, in part because, in most education systems, it is difficult to have the same student samples available for further examinations a long time after the experimental courses finish. Among the few available, Francis et al. (1998) and Bernhard (2001) show that college-level students achieve better long-term results if their instruction is based on research-based curricula, as compared with those students following traditional, lecture-based instruction. Similar results were achieved by Kohlmyer et al. (2009) and Pollock (2009) on regular college courses and by Benegas and Sirur Flores (2014), working with high school students of a very different education system. Persano Adorno et al. (2018) also report on long-term learning, but in a different type of experiments, based on supplementary, post-instruction active-learning activities. These experiences, taken as representative of studies run in different education systems and school levels, not only point out the beneficial effects of active-learning instruction, as compared with teacher-centered pedagogies, but also to the difficulties of running this type of longitudinal studies. Although the above experiments are based upon the application of the same test at two different times after instruction, they are based on the time changes of the average class performance and not on the evolution of individual student's answers to every test item, as proposed in the present work.

For several reasons, accurate determination of long-term learning is a relevant issue, in particular for assessing the effectiveness of instruction. For instance, in most Latin American countries, long-term scientific knowledge does not seem to be the usual outcome of high school instruction. According to the results of international PISA evaluations (OECD, 2019), the conceptual knowledge of regional middle school students is extremely low, with participating Latin American countries at the bottom of the world-wide performance scale. An Ibero-American study (Benegas et al., 2009; 2010) that complemented the PISA measurements, showed that just about 7% of more than 3,000 first-year science and engineering university students, attending seven universities in five different countries, have a sound conceptual knowledge of Coulomb´s law. With similar disappointing results obtained in all other tested topics, including free-fall motion, Newton´s laws, and simple dc electric circuits, all basic subjects included in the standard high school physics curricula of all participating countries. Since all these students had obtained passing grades in their high school general science and physics courses, but at the beginning of their university studies (In science and engineering!) their conceptual knowledge was so low, the immediate question regards how solid was the knowledge acquired in the corresponding high school instruction.

Towards this educational problem, this work proposes a new approach for measuring long-time conceptual learning based on the after-instruction evolution of students´ answers to a research-based, multiple-choice, single-response (RB-MCSR) test. The method follows the work of Lasry et al. (2014) who proposed the use of RB-MCSR tests to measure gains and losses of conceptual understanding by analyzing, for every test item, the options selected by each student before and after instruction.

Following a similar procedure, we propose that appropriate categorization of student´s answers to two after-instruction administrations of the same RB-MCSR test should provide an accurate measurement of long-term and temporary learnings. Therefore, this work has the following research objectives:

1. To present a method to measure long-term and temporary learnings based on the after-instruction evolution of students´ answers to individual items of RB-MCSR tests.

2. To apply this method to a group comparison classroom experiment to compare the long-term learning outputs of two different instructional approaches.

Conceptual Knowledge and Research-Based, Multiple-Choice Tests

This work is based upon the assumption that research-based, multiple-choice, single-response tests are not only a representative measure of conceptual knowledge but also a sound way to follow the evolution of the main learning difficulties and alternative models held by a given student group. The most representative RB-MCSR tests in physics and other STEM disciplines (https://www.physport.org/assessments/), have been constructed with questions that probe different aspects of a given subject. It is important to note that, for each question, the distractors (the wrong options) correspond to the most popular alternative models and learning difficulties on the tested subject. These distractors, which have been revealed by extensive qualitative and quantitative educational research on university and high school students of different school systems (see, for instance, Hestenes et al., 1992; Engelhardt & Beichner, 2004), are applied to close to everyday situations, appealing to students´ previous experiences even if they have not yet been exposed by instruction to the corresponding scientific concepts. In that regard, Bao & Redish (2006) in their model analysis, recalled that educational research has shown that alternative conceptions of a particular topic seemed to be limited to a few popular models and that different contexts -including students' mental state- could activate different, even contradictory conceptions (di Sessa, 1993; Vosniadou, 1994). Therefore, an individual with a solid scientific framework (Newtonian, for instance) should ideally answer all items in a consistently correct manner, but others -especially uninstructed participants- could choose different wrong answers, even shifting from one distractor to another without a solid reason or being particularly aware of the contradiction. In this framework, alternative models, which derive their resilience from their association with underlying presuppositions in students´ previous knowledge, should not be considered as deeply held specific theories. Consequently, students may change their local, situational models, moving from one distractor to another influenced by the context, without the need to be internally consistent. Considering furthermore, that RB-MCSR tests are relatively easy to apply, analyze and compare local results with those of other applications, it is clear that the use of RB-MCSR tests provides both practical applicability and sound pedagogical bases to the present approach.

Methods

The Classroom Experiments

To test the suitability of the proposed method and as an example of the type of data to be analyzed, we propose to study the after-instruction dynamics of high school students´ answers to an RB-MCSR test. To that end, a quasi-experimental group comparison study was designed, with pre- and post-instruction evaluation. The subject, simple resistive electric circuits, was taught to two 11th grade high school classes of a state-run mixed-gender school, attended by students coming from low to middle-class families. CTRL and EXP groups have N_{TRD}= 31 (15 females) and N_{EXP} = 30 (14 females) students, respectively, a rather common condition of local high schools. Students were assigned to each class following institutional rules, two years before the experiment. For this experiment one of the classes (called TRD heretofore) was randomly assigned to the traditional, teacher-centered instruction offered in previous years. The other class (EXP) followed an experimental instruction that used the instructional activities of the active-learning methodology Tutorials for Introductory Physics (Tutorials) (McDermott & Shaffer, 1998)._The evidence-based learning effectivity of Tutorials (Redish & Steinberg, 1999) determined its selection as the experimental teaching approach. Its learning cycle: *elicit* students´ previous ideas, *confront* them with the outcome of the Tutorials Worksheets and *resolve* the differences, is implemented through three complementary activities: Tutorial Pre-test, Tutorial Worksheet, and Tutorial Homework. Students in the EXP class, following this sequence, worked through two Tutorials didactic units: "A model for circuits Part 1: Current and resistance" and "A model for circuits Part 2: Potential difference". Pre-test and Homeworks are individual activities carried out outside the classroom, while the Tutorials Worksheets were worked out by small collaborative groups of 3-4 members in the regular classroom settings. To that end, students in each small group moved their desks so that they could face one another, building up in this way small working tables for circuit elements and paperwork. The traditional instruction consisted of demonstration-supported lectures and problem-solving sessions. The latter consisted of exemplary problem-solving demonstrated by the teacher, followed by students´ problem-solving individual practice. Homeworks consisted mainly of problem-solving activities. In both teaching approaches, Homeworks contributed to students´ grades. Both courses were taught by the same experienced teacher, who had previously participated in a Tutorials workshop.

Conceptual knowledge of the subject matter was measured through the application of the RB-MCSR test Determining and Interpreting Resistive Electric Circuits Concepts Test (hereafter DIRECT) (Engelhardt & Beichner, 2004). For this experiment this measuring instrument was applied after instruction at two different times: just at the end of instruction (Post I) and one year later (Post II). The time between Post I and Post II was determined by the availability of the students´ samples, with Post II given about one year after instruction, in the last month of these students´ high school studies. Therefore, "long-term learning" in this study case should be interpreted as the knowledge retained one year after instruction. Pre- and Post-instruction performances are used to calculate the normalized gain g, defined as g= (Post-Pre)/(100-Pre) (Hake, 1998). For the present case, we can define a "short-term" normalized gain g_I, using Post I to calculate g, and a long-term normalized gain, g_{II}, determined using Post II to calculate g.

Although in all test applications the full test (29 items) was given to students, for the present application only the 19 items (listed in Table 1) directly related to the taught subject were analyzed, excluding, for instance, those items related with energetic and microscopic aspects of electric circuits.

Equivalency of these institutionally formed groups was determined by their similar gender and socio-economics conditions, as well as their common previous experience in science and math courses. Equivalency in the subject matter was determined by the pre-instruction application (Pre for shorthand) of the test DIRECT. Average (and standard deviation) pre-instruction performances were 20(10)% for the CTRL group and 12(7)% for the EXP group, i.e., very close or lower than the random performance, pointing to the very low initial students´ knowledge about this subject. Even though an independent sample t- test found some statistical evidence of differences of pre-instruction knowledge between the two groups ($t= 3.785$, $df= 59$, $p< 0.001$), for the present experiments they are considered equivalent groups since their very low pre-instruction performances indicate a practically null initial knowledge of electric circuits in both courses.

Determining Long-Time Learning

The distinction between temporary, short-term, and stable, long-term learnings is a central issue in education. Soderstrom & Bjork (2015), for instance, discusses temporary and long-term learning in terms of *Performance* and *Learning*. In their framework, *Learning* refers to relatively permanent changes in knowledge or behavior, a primary goal of instruction. *Performance*, on the other hand, refers to temporary fluctuations in student´s knowledge as measured or observed during (or shortly after) instruction.

This work proposes that proper categorization and analysis of all possible (Post I, Post II) answer pairs, obtained from two post-instruction applications of the same RB-MCSR test, should provide a quantitative measurement of long-time and temporary learnings. The basic idea is to assign a plausible learning path to every possible correct/incorrect combination of (Post I, Post II) answer pairs. It is postulated that students acquiring stable, long-term learning, should systematically select, after instruction, the correct option, i.e., the appropriate scientific model. Temporary, short-term learning, on the other hand, corresponds with those students that, choosing the correct option immediately after instruction, return to an incorrect option (an alternative conception) a certain time afterward. To complete this picture, some students will, after instruction, systematically chose incorrect options. In the present model, it will be assumed that this fraction of students has failed to learn. Consequently, the following interpretation is proposed for the relative abundances of the five possible correct/incorrect (Post I, Post II) answer pairs:

CC: a *correct* answer immediately after the instruction (Post I), which is maintained a long time later (Post II), denotes a solid, stable scientific knowledge. This CC fraction is postulated to be the quantitative measure of long-time learning.

CI: a *correct* answer immediately after the instruction that turned *incorrect* later is attributed to labile, temporary learning.

$II_=$ and $II_{\neq}$: these *incorrect-incorrect* answer pairs denote the after-instruction presence and persistence of learning difficulties and alternative models. In particular, $II_=$, which measures the fraction of times the same wrong option is selected in both after-instruction test applications, indicates the presence of a very strong, prevalent alternative model, firmly held by students after instruction. Instead, the fraction of answers with different incorrect options, measured by $II_{\neq}$, indicates that students shifted between different distractors (alternative models) in Post I and Post II. In this framework, the total fraction of *incorrect-incorrect* answer pairs, $II_= + II_{\neq}$, is interpreted as a quantitative measure of the failure to learn.

IC: this answer pair corresponds to students that selected an *incorrect* option just after instruction and the *correct* answer in Post II. If the tested subject was not revisited by instruction in the time between Post I and Post II (and consequently no new learning is expected to have occurred in that period), it is assumed that this pair does not represent real knowledge at the time of Post II. Consequently, this answer pair is considered a measure of the experimental error inherent to the use of MCSR tests.

As an example of the type of analysis proposed in the present work, Figure 1 shows the evolution, from Post I to Post II, of students´ answers to Item 22 of DIRECT (Engelhardt & Beichner, 2004) in the CTRL and EXP classes.

Data represented in Figure 1 allow us to identify a few relevant features of the after-instruction evolution of students' answers to this particular item. For the CTRL class the main findings are:

1. The few after instruction (Post I) correct answers (6) changed to incorrect one year later (CI=6).

2. The two correct answers, given one year after instruction, corresponded to incorrect answers in Post I (IC=2).

3. Most incorrect answers given immediately after instruction (Post I) evolved to a different incorrect option one year later ($II_{\neq}$ = 18), which is about three times the number of same incorrect options in both tests ($II_=$= 5).

For the EXP sample, the situation is quite different:

1. Correct-correct is the most abundant answer pair (CC=15).

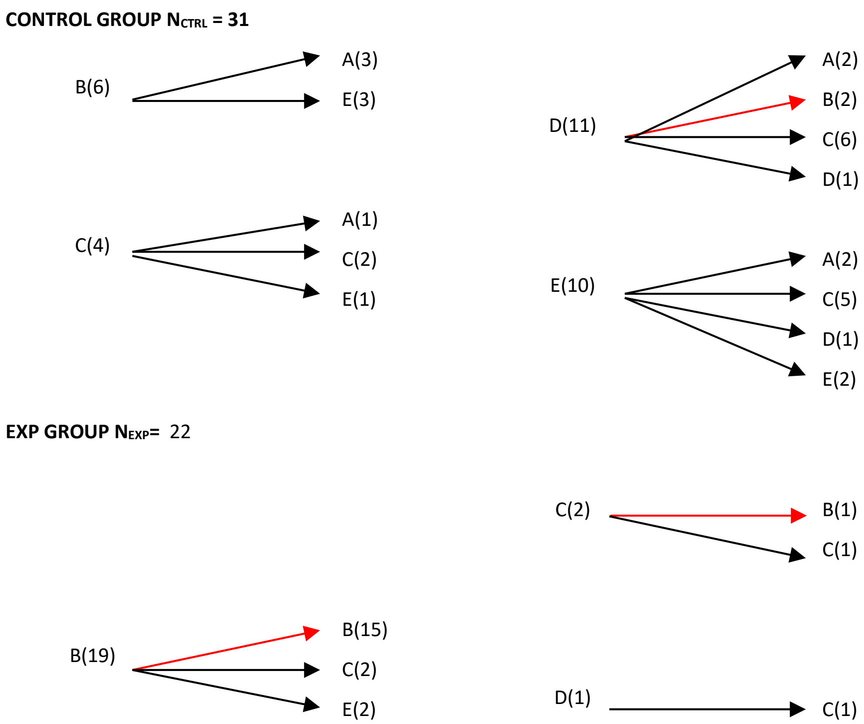
2. Only four initially correct answers turned incorrect (CI=4).

3. A very low number of incorrect-incorrect answer pairs ($II_{\neq}$ = 1 and $II_=$= 1)

4. Non-significant number of incorrect to correct answer pair (IC= 1)

Figure 1

Evolution of Students´ Answers to Item 22 of the Test DIRECT from Post I to Post II



Note. For each answer choice (A to E) the numbers within parenthesis indicate the number of students selecting that choice. Arrows indicate how the answers in Post I evolve to Post II. Correct Answer: B.

A similar analysis of the other test items, and normalizing by the total number of answer pairs, allowed us to calculate the course average abundances of the five answer pairs shown in Table 1. Although it is beyond the scope of this work, this procedure also allows for more in-depth studies. Analysis by learning objective/dimension or by learning difficulty/alternative model can be readily carried out because the authors of the relevant RB-MCSR test usually identify or separate the test items in that manner. Similarly, the method could also be used to study different factors that might influence the learning processes, such as prior knowledge, reasoning ability, interest, academic achievement, self-concept, gender, and so on. The time series can also have more than two points, searching for the characteristics of the processes determining the loss of knowledge with time.

Results

The results of this experiment, separated for the CTRL and EXP groups are summarized in Table 1, which shows the statistical parameters of the traditional and new methods. The test items have been arranged according to the learning objectives proposed by the DIRECT test (Engelhardt & Beichner, 2004), relevant to the present experience: ¨Physical Aspects of DC Circuits" and "Current and Voltage." For each student´ group, the bottom row shows the corresponding whole class average results for the 19 items of DIRECT under analysis here. Columns 3 to 7 correspond to the statistical parameters calculated following a traditional MCSR test analysis: Pre, Post I, and Post II average course performances, and the corresponding normalized gains g_I and g_{II}. A simple inspection of Table 1 shows, in both groups, a rather similar performance behavior for both objectives, with small variations respect the total (bottom) row. A first general result is the important after-instruction performance difference between the two groups in both DIRECT objectives and for all tested items. An independent samples t-test shows that the Post I average performance of the EXP group is statistically higher than the CTRL sample performance ($t=5.573$, $df=59$, $p<0.001$). Similar results are found for the one-year after-instruction performances ($t=6.901$, $df=51$, $p<0.001$), which determine an effect size (Connolly, 2007) of 0.698 for the long-term performances. The difference in df happens, as noted in Methods, because 8 students of the EXP sample were absent at the time of the Post II evaluation, therefore the one-year after-instruction statistical parameters were calculated over the 22 students of the EXP sample that participated in all tests. The last row of each group also shows how time affects knowledge, with a mean performance drop of about 20% between Post I and Post II in both samples. This performance drop results in a drop in the normalized gains, $Dg= g_{II} - g_I$, of about -0.20, also very similar in both samples.

Table 1

Average Students´ Performances and Relative Abundances of the Five (Post I, Post II) Answer Pairs by Objective of the Test DIRECT.

DIRECT OBJECTIVE	Item #	Pre	POST I	POST II	g_I	g_{II}	CC	CI	$II_=$	$II_{\neq}$	IC
				CTRL Group							
Physical aspects of DC Circuits	4,5,9,10,13,14,1819, 22,23,27	21	40	20	0.24	-0.01	10	30	12	38	11
Current and Voltage	6,8,15,1617,26,28, 29	18	38	21	0.24	0.04	11	27	16	36	10
TOTAL	All tested items	20 (10)	39 (20)	21 (13)	0.24	0.01	10 (12)	28 (10)	14 (9)	37 (16)	11 (6)
				EXP Group							
Physical aspects of DC Circuits	4,5,9,10,13,14,1819, 22,23,27	13	74	55	0.70	0.48	50	24	5	15	6
Current and Voltage	6,8,15,1617,26,28, 29	10	62	40	0.58	0.33	38	35	12	14	2
TOTAL	All tested items	12 (7)	68 (22)	49 (16)	0.64	0.42	44 (20)	29 (13)	8 (7)	14 (12)	4 (5)

Note. Columns, from left to right, indicate DIRECT learning objective, DIRECT items that evaluate that objective, percent values of the average class performances in Pre, Post I, and Post II. The next two columns to the right indicate the normalized gains g_I (Post I relative to Pre) and g_{II} (Post II relative to Pre). The last five columns on the right show the percent values of the Correct-Correct, Correct-Incorrect, Incorrect-different Incorrect, Incorrect-same Incorrect and Incorrect-Correct, (Post I, Post II) answer pairs. TOTAL row represents the corresponding mean values (and standard deviations) over all tested items

The results of the present approach are represented by the (Post I, Post II) answer pairs shown in the last five columns on the right of Table 1. The first, striking result is the large difference in the CC pairs. Another feature is that these data show again, in both samples, similar behaviors by objectives and for the total of tested items. For the CTRL sample, Table 1 shows that about half (51%) of the answer pairs correspond to the incorrect-incorrect group, most of them of the different-incorrect options subgroup ($II_{\neq}$ = 37 %). Short-lived learning (CI) represents the second most relevant group (28%), while only 10% of the answers correspond to the CC pair, which measures long-time learning. The situation is very different for the EXP sample, where long-time learning is the most abundant category (CC=44%), i.e., after instruction almost half of the time these students systematically selected the correct answer. The CI answer pair, representative of short-lived learning, is again almost 30 %, while the fraction of incorrect-incorrect answer pairs is reduced by a factor of two, to 22%. It is also observed that, within our statistics, the EXP sample showed some preference for selecting, in both tests, the same wrong model ($II_{\neq} = 1.5\ II_{=}$), as compared to the CRTL sample ($II_{\neq} \sim 2.6\ II_{=}$). An independent sample t-test on the CC pair performance shows that there is a significant difference between these two samples concerning the selection of the CC pair ($t=8.835$, $df=51$, $p < 0.001$). If students are grouped according to their CC performance, it is found that 61% of the CTRL sample selected only between 0 and 10 % of CC pairs, with another 26% of this sample selecting between 10% and 30 % of the time a CC pair. The situation is almost reversed in the EXP sample where 50% of the sample selected CC pairs more than 50% of the time, with another 23% of this group selecting CC pairs between 30% and 50% of the time. These findings are reinforced by calculation of the loss parameter, L= CI/(CI+CC) (Lasry et al., 2014), which indicates the fraction of correct answers in Post I that turned incorrect in Post II. Data from Table 1 yields L_{CTRL}= 0.79 (0.19) and L_{EXP}= 0.39 (0.13), i.e., losses in the CTRL group double losses in the EXP group, pointing again to the labile nature of learning generated by traditional instruction.

Discussion

This work presents an alternative method of calculating long-term learning using data from a longitudinal study consisting of two post-instruction applications of the same RB-MCSR test. Traditional analysis, represented by the Pre, Post I, Post II, g_I, and g_{II} data of Table 1, indicates that some knowledge is lost with time and that this loss can be measured as the difference between Post I and Post II, or through the differences between the corresponding normalized gains g_I and g_{II}. Large differences between the two samples are observed in the Post I and Post II data. Surprisingly, the CTRL sample returned, one year after instruction, to the very low pre-instruction knowledge. This fact is reflected by the almost null value of long-term normalized gain g_{II}. Much to the contrary, the corresponding learning parameters of the EXP group show an important knowledge level, even one year after instruction.

The new approach presented in this work allows for more in-depth analysis. For instance, Table 1 shows that the important changes in long-time learning between the two groups are due to the large difference in the "no-learning" groups – about 50% in the CTRL sample -, which is reduced by a factor of two in the EXP sample. If we imagine these three learning categories as steps of a "learning ladder," our data suggest that about 25-30% of the EXP sample has moved one-step up this ladder as compared to the CTRL sample. This change results in a notable (four times) increase of the fraction of answer pairs denoting durable learning, but with similar values of the temporary learning (the CI pair).

The relative abundance of the no learning categories is also worthy of analysis. While in the EXP group there is a clear predominance of same-incorrect distractors, in the CTRL group the number of students choosing the same-incorrect options is about 1/3 of those selecting different-incorrect answer pairs, which seems to indicate no preference for a particular distractor (in this test with four distractors/item). In terms of the Model Analysis of Bao and Redish (2006), the EXP group seems to be challenged by one prevalent learning difficulty (pure, but incorrect, model state in that framework), while answers in the CTRL group shifted between different-incorrect models, showing no preference for a particular alternative model (mixed model state). In that regard, Bao and Redish (2001) showed that the presence of two or more relevant distractors, implying that most students don't have a strong preference for any model on this topic, results in responses close to random guesses. This combination of *l*ow performance and *l*ow concentration of answers on a given option (the LL region in their model) characterizes uninstructed student samples. This position seems to confirm that, one year after instruction, there is little sign of the instruction received by the CTRL sample.

Finally, Table 1 shows the IC pair is more than twice larger for the CTRL sample compared to the active learning class. Since no instruction on the tested subject was given in the period between Post I and Post II, it has been assumed that this answer pair should not be considered as real understanding at the time of Post II. Consequently, it has been interpreted as the experimental error intrinsic to the use of multiple-choice tests. This position seems also supported by the adopted learning model (Bao & Redish, 2006; di Sessa, 1993; Vosniadou, 1994), which postulates that individuals that have not acquired the scientific model (the fraction of wrong answers in Post I) might change their answers without being particularly aware of it. In other words, we can assume that the evolution of their answers from Post I to Post II should be close to random. If this were the case, the measured IC pair should be the result of all incorrect answers in Post I that evolve randomly to Post II, yielding, for the present case, a value of the IC pair of 0.06 for the EXP group and 0.12 for the CTRL group, i.e., very close to the IC values shown in Table 1. According to this interpretation and values of the IC answer pair, the measuring error also seems to depend on the effectiveness of the teaching strategy.

Although the aim of this work is about measuring long-time, durable learning, it seems worthwhile to highlight a few points from the instructional point of view. First, and despite the large differences in the efficiency of the two teaching strategies, it is clear that even adopting a successful active-learning pedagogy, there is plenty of room for improving learning outcomes. As noted above, one out of three answer pairs selected by students of the EXP sample denotes short-lived learning. Considering labile learning as a transition state between the absence of learning and long-lived learning, it is clear that a relevant fraction of learners accomplished only precarious, unstable learning, and that further actions should be taken to consolidate the scientific model. In this regard, and since active learning teaching strategies are based on pedagogical principles that foster deep learning (Biggs, 2003; Meltzer and Thornton, 2012; Prosser and Trigwell, 1999), a reasonable recommendation is to strengthen this teaching position. One straightforward approach is to use complementary active learning strategies in the different activities of a given course (lectures, problem-solving, labs, etc.). This simple pedagogical approach, much in line with that proposed, for instance, by the Activity Based Physics Suite (Redish, 2003; The Physics Suite, 2015) explicitly avoids the drawbacks of the simultaneous use of conflicting learning approaches (Guidugli, Fernandez Gauna and Benegas, 2005). In the present case, for instance, the two Tutorials on DC circuits used by the EXP class could be complemented with the Interactive Lecture Demonstrations (Sokoloff and Thornton, 2004) "Introduction to DC circuits" and "Series and Parallel Circuits." This small change should provide further learning opportunities using only two extra hours of teaching time. Since these active learning strategies make use of coherent pedagogical principles to confront students with their learning difficulties, this approach should also be efficient for improving learning in the "no-learning" group.

Conclusions

The aim of this work has been to present a simple and more accurate approach to determine the fraction of students that, after instruction, achieve a solid long-term knowledge as compared to those getting only temporary, short-lived learnings. The method, based on the categorization of all possible answer pairs obtained from two after-instruction applications of a research-based MCSR test, readily provides not only a quantitative determination of long-term and temporary learnings but also the fraction of answer pairs associated with the absence of learning. Furthermore, the method allows separation of the "no-learning" group into two categories, i.e., those students that, after instruction, systematically selected the same incorrect option from those that shifted between different distractors. As noted in the previous sections, these features could furnish relevant insights regarding the characteristics of the learning obstacles faced by students.

Even though in the present classroom experiment both methods of analysis show that long-time conceptual learning is clearly higher in the experimental group, the new approach is more accurate than the standard determination of enduring learning. For instance, if one takes the results of Post II (Table 1) as a measurement of long-time learning, the achievement of the CTRL class would be overestimated by a factor of two (21% performance in Post II vs 10% of the CC pair). On the contrary, a similar comparison for the EXP sample results only in a 10% difference (49% vs. 44%, respectively). Since the IC pair, interpreted here as the experimental error, has been shown to depend on the type of instruction, the above results seem to confirm this dependence of the measuring error on the effectiveness of instruction. In terms of Soderstrom & Bjork (2015) model, the classical determination of *Learning* would be given by the results of Post II. The present model allows us to refine this measurement, correctly assigning the CC answer pair value to this long-time learning, leaving out the experimental error contribution to Post II.

The extremely low long-lasting learning achieved by the CTRL group could not be just idiosyncratic of the student groups analyzed in this study. Similarly, low conceptual knowledge (about 10%) has been reported for all relevant areas of basic physics (force and motion, free-fall motion, and Coulomb´s Laws) by the broad study cited above (Benegas et al., 2009; 2010). Although belonging to different school systems and countries, the common point of these student samples of first-year university students is that they had been subjected to traditional, lecture-based high school instruction. Therefore, the above results of the CTRL group provide a plausible explanation for the surprisingly low level of conceptual understanding, uniformly shown by these samples of incoming university students. In this regard it is noted that, since the proposed method is easily applicable to large-scale assessments, it should be of help to school officials that very frequently need an easy-to-use tool to measure the real, enduring impact of instruction on students´ conceptual knowledge.

Overall, this analysis makes clear that a substantial amount of basic and applied educational research is needed to improve our knowledge of the processes leading to solid, long-lasting conceptual learning, and to develop teaching approaches to achieve this goal. We think that these educational issues deserve further research and that the novel approach for measuring long-time learning presented here might be of help for designing and carrying out appropriate experiments.

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